PROCEEDINGS

OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES

VOL. LXXVIII

INCLUDING RECORDS

FROM OCTOBER 1949 TO MAY 1950

BOSTON:

PUBLISHED BY THE ACADEMY

1949–1950

CONTENTS

Proceedings of the American Academy of Arts and Sciences

Vol. 78, No. 1, P. 1–35—February, 1950

CENTENNIALS AND POLYCENTENNIALS OF CHEMICAL INTEREST DURING 1950

Ernest H. Huntress

Massachusetts Institute of Technology
Cambridge, Massachusetts

CENTENNIALS AND POLYCENTENNIALS OF CHEMICAL INTEREST DURING 1950

ERNEST H. HUNTRESS

Massachusetts Institute of Technology
Cambridge, Massachusetts

Received November 3, 1949

This paper draws to the attention of alert teachers and students of science in general and chemistry in particular certain anniversaries which occur during the year 1950 of the birth or death of certain important figures. The mode of presentation is essentially the same as in the corresponding treatment[1] for the preceding year. Attention is called to the fact that the citations accompanying most of the biographical digests indicate the location in the periodical literature of portraits and photographs of the subjects, a service not anywhere else available. These are classified as P_1, P_2, and P_3 in diminishing order of quality, the first category being reserved for full-page pictures printed on only one side of the sheet and often on special paper. Although no attempt has been made to distinguish between biographies, jubilees, obituaries, memorials or other characterizations, all being designated by B, the order in which they are listed corresponds in a diminishing sequence to the present author's opinion of their relative importance as source material.

Of the twenty-seven individuals comprising this treatment for the year 1950, nineteen are 100-year anniversaries, five are 150-year memorials, while the remaining three represent celebrations of 250, 300 and 400 years, respectively.

RED LETTER DAYS DURING 1950

——	Quadricentenary of birth of J. NAPIER
Jan. 13	Centenary of birth of C. F. MABERRY
Feb. 7	Centenary of birth of J. B. F. HERRESHOFF
Feb. 9	Sesquibicentenary of birth of D. BERNOUILLI
Feb. 11	Sesquicentenary of birth of W. H. F. TALBOT
Feb. 11	Tercentenary of death of R. DESCARTES
Feb. 13	Centenary of birth of J. W. BRÜHL
Feb. 26	Centenary of birth of J. J. HUMMEL

[1] Huntress, "Centennials, Sesquicentennials, and Bicentennials of Chemical Interest During 1949," Proc. Am. Acad. Arts Sci. 77, 35–54 (1949).

Mar. 3	Centenary of birth of Z. H. SKRAUP
Apr. 1	Centenary of birth of H. VON PECHMANN
Apr. 8	Centenary of birth of W. H. WELCH
May 9	Centenary of birth of E. WESTON
May 9	Centenary of death of J. L. GAY-LUSSAC
May 13	Centenary of birth of O. HEAVISIDE
May 29	Centenary of birth of G. GOLDSCHMIEDT
June 6	Centenary of birth of K. F. BRAUN
July 15	Sesquicentenary of birth of J. B. A. DUMAS
July 31	Sesquicentenary of birth of F. WÖHLER
Aug. 7	Centenary of birth of A. R. M. HENNIGER
Aug. 26	Centenary of birth of C. R. RICHET
Aug. 30	Centenary of birth of F. HOFMEISTER
Sept. 5	Centenary of birth of E. GOLDSTEIN
Sept. 22	Sesquicentenary of birth of J. L. LASSAIGNE
Oct. 8	Centenary of birth of H. L. LECHATELIER
Nov. 20	Centenary of birth of O. G. DOEBNER
Dec. 12	Centenary of death of G. H. HESS
Dec. 29	Sesquicentenary of birth of C. GOODYEAR

NAPIER, JOHN

Born 1550, at Murchiston, near Edinburgh, Scotland; died April 4, 1617, at Murchiston.

John, the eighth Napier of Murchiston, was born when his father, Archibald, was little more than 16 years old. John Napier matriculated at St. Salvator's College, St. Andrews University, in 1563 but did not remain there to graduate since before 1566 he departed for study in Paris, and travel in Italy and Germany. He had returned to Scotland, however, by 1571. By his first marriage (1572) he had a son and a daughter and after the death of his first wife a second marriage (1579) gave five sons and five daughters, of whom the second son, Robert, became his literary executor.

Napier as an ardent Protestant took an active part in church politics and in 1593 (4) published, under the title, "a plaine discovery of the whole Revelation of St. John," a book now regarded as of considerable importance in the history of Scottish theology, and which at the time passed through several editions in English, French, German, and Dutch. He seems next to have been occupied with various military inventions, no doubt stimulated by the generally expected invasion by Philip of Spain, for in 1596 he described a mirror for setting fire to hostile vessels, a piece of artillery for destroying everything around the arc of a circle, and a round metal chariot such that it could rapidly and

easily be moved by its occupants while firing shot out through small orifices.

In July, 1614, Napier published a volume entitled, "Mirifici Logarithmorum Canonis Descriptio," wihich contained the first description of the nature and use of logarithms (to which he gave this name), and the first logarithm table (comprising to seven figures his values of the logarithms of the sines of angles). This book was translated into English by Edward Wright, whose work was posthumously published (1618) by his son Samuel Wright. The methods by which Napier had arrived at the important results embodied in the "Descriptio," though actually written previous to it, were nevertheless first disclosed in a second book, "Mirifici Logarithmorum Canonis Constructio," published (1619) after Napier's death by his son Robert and translated (1889) into English by W. R. MacDonald.

The logarithms introduced by Napier in the "Descriptio" are not the same as those now designated as Naperian or natural logarithms, and also differ from the present common decimal logarithms. The transposition of the original logarithms to the decimal system was contemplated by Napier himself but actually first consummated by Henry Briggs, Gresham Professor of Geometry in London, who first published the results about 1617.

Napier also devised a method of multiplication and division using so-called enumerating rods later known as "Napier's bones." His name is also associated with certain aspects of spherical trigonometry and with the independent discovery of the use of the decimal point in arithmetic although it had also been employed by Pitiscus in the tables (1612) of his "Trigonometria."

An international congress held in Edinburgh in July, 1914, to commemorate the tercentenary of the publication of the "Descriptio" resulted in the publication in 1915 by the Royal Society of Edinburgh of a Napier Tercentenary Memorial Volume edited by the Society's secretary C. G. Knott. An extraordinary collection of portrait and biographical references is given in Archibald's "Mathematical Table Makers," pp. 59–63 (1948).

P_2 Ann. Rept. Smithsonian Inst. for 1914, 175–181 (1915). B Dict. Natl. Biog. *40*, 59–65 (1894).

MABERRY, CHARLES FREDERIC

Born Jan. 13, 1850, at New Gloucester, Maine; died June 26, 1927, at Portland, Maine.

Chemical training at Lawrence Scientific School of Harvard University under Josiah P. Cooke led to Mayberry's doctorate in 1876. Subsequently (1883) he became Professor at Case School of Applied

Science in Cleveland, Ohio, where he remained continuously until his retirement (1911). During this period published with a student (H. H. Dow) a paper which developed into Dow process for extraction of bromine from brine.

Maberry is best known as a pioneer in study of petroleum. These studies, which began in 1887 and continued until long after his retirement, comprised theoretical approaches to the geochemical origin of petroleum, practical investigations of lubricants and lubrications, and extensive inquiries looking to the identification of the constituents and establishment of the composition of American petroleum.

P_3B Ind. Eng. Chem. *15*, 314 (1923): Ind. Eng. Chem., News Ed. *5*, 5 (July 10, 1947): B J. Chem. Education *5*, 1117–1120 (1928): B Natl. Cycl. Am. Biog. *10*, 411 (1909): B Dict. Am. Biog. *11*, 540 (1933).

HERRESHOFF, (JOHN BROWN) FRANCIS

Born Feb. 7, 1850, at Bristol, Rhode Island, died Jan. 30, 1932, at Atlanta, Georgia.

This Anerican chemical engineer and metallurgist was the sixth and youngest son of a famous Rhode Island family. One of his older brothers, James Brown Herreshoff (March 18, 1834—Dec. 5, 1930) was a distinguished inventor; two others, John Brown Herreshoff (April 24, 1841—July 20, 1915) and Nathaniel Greene Herreshoff (March 18, 1848—June 2, 1938) became world renowned ship designers and builders. For several decades they supplied the racing yachts which defended the American Cup established (1857) as a perpetual international challenge trophy.

J. B. Francis Herreshoff attended Brown University in near-by Providence, Rhode Island, with the class of 1870. He served (1867–1868) as chemical laboratory assistant and (1869–1872) as assistant professor of analytical chemistry. Many years later Brown University awarded him successively with three honorary degrees, an A.M. (1890), Ph.B. (1905 by special vote), and eventually (1909) the D.Sc.

After several miscellaneous associations with chemical industry he was selected (1875) by William H. Nichols as superintendent of the Laurel Hill Chemical Company of Long Island, N. Y., and during the subsequent fifty years of his professional life was a pioneer in the development of sulfuric acid manufacture. During all of this period he was connected with one or another of the Nichols chemical enterprises and subsequent to their merger (1899) into the General Chemical Company served as its consulting engineer until his retirement (1924).

Mr. Herreshoff early devoted his attention to copper smelting and

invented (1883) an important type of steel-enclosed, water-jacketed smelting furnace. Soon thereafter he obtained at age 36 three American patents which substantially revolutionized the sulfuric acid industry. The first (U. S. 335,699, Feb. 9, 1886) comprised the Herreshoff tower which made possible the attainment of much higher acid concentration than previous practice. The second (U. S. 357,528, Feb. 8, 1887) represented a new process, and the third (U. S. 369,790, Sept. 13, 1887) a new apparatus for further increase in acid concentration. Still later he effected developments which established the contact process for sulfuric acid manufacture in the United States. He invented (1896) the roasting furnace for fine pyrites ores which still bears his name, was led into studies on the recovery of copper from the cinder, and developed in collaboration with W. C. Ferguson a process for removal of even minute amounts of impurities from copper. As a result of his work the Nichols companies were by 1900 producing daily 1,000,000 pounds of electrolytic copper or about one-fourth of the world's output at the time. Because of its high purity such copper was used in preference to that of Lake Superior origin in construction of the Atlantic cable.

In recognition of his great contributions to the science and technology of these important chemical and metallurgical processes Herreshoff became (1908) the first American to receive the now famous Perkin Medal of the New York Section of the (British) Society of Chemical Industry. This honor also comprised the second award of this medal which had been established (1906) in honor of Sir William H. Perkin, himself its first recipient.

P_3B Ind. Eng. Chem. *19*, 1205–1206 (1927): P_3B Electrochemical and Metallurgical Industry *6*, 51–54 (1908): B J. Soc. Chem. Ind. *27*, 265–271 (1908): P_3B Ind. Eng. Chem., News Ed. *10*, 29 (1932): P_1B Natl. Cycl. Am. Biog. *24*, 96 (1935).

BERNOUILLI, DANIEL

Born Feb. 9, 1700 (New Style) at Gröningen, Netherlands; died March 17, 1782, at Basel, Switzerland.

The Swiss Bernouilli family, which in three generations produced eight mathematicians, had no fewer then 120 descendants of whom none was a failure and the majority achieved distinction, sometimes amounting to eminence in various fields. Daniel, a son of Johann Bernouilli (1667–1748), is said to have begun at 11 the study of mathematics under the tutelage of his brother Nicolaus III, only five years older than himself. Although pressed by his father to enter business, Daniel first studied medicine, yet accepted (1725–1733) a mathematical post at the Russian Academy in St. Petersburgh.

Irked, however, by the comparative barbarity of life in Russia, he returned to Switzerland, where at the University of Basel as professor of anatomy and botany (1733–1750) and later of physics and natural philosophy (1750–1777) he spent 44 years, finally with advancing years resigning in favor of his brother's son, Daniel Bernouilli the younger.

Daniel Bernouilli is regarded as the father of mathematical physics. His interests included the calculus, differential equations, theory of probability, theory of vibrating strings, and the kinetic theory of gases. His principal work was the "Hydrodynamica" (1738) in which, based on a recognition of the principle of the conservation of energy, he considered from both theoretical and practical viewpoints the behavior of fluid flow and formulated the theorem of fluid pressure which still bears his name.

He won no less than ten prizes from the French Academy of Sciences, including at least one for which his father also competed, and was elected (1750) to the Royal Society of London.

TALBOT, WILLIAM HENRY FOX

Born Feb. 11, 1800, at Melbury, Dorsetshire, England; died Sept. 17, 1877, at Lacock Abbey, near Chippenham, Wiltshire, England.

This British country gentleman received his education at Harrow (1811–1815) and at Trinity College, University of Cambridge, where he attained B.A. (1821) and M.A. (1825). His subsequent work in photography has rather obscured his earlier accomplishments in mathematics, physics and astronomy but these were sufficient to cause his election (1831) at age 31 to the Royal Society of London. He was with Rawlinson and Hincks one of the earliest to decipher the Assyrian cuneiform inscriptions at Nineveh. He was for two years (1832–1834) a member of Parliament and throughout his life an extensive traveler. A monument to his memory has been erected on his estate at Lacock Abbey [Phot. Korr. *58*, 236 (1912)] and a collection of his apparatus has been presented to the Museum of the Royal Photographic Society in London.

His chief contribution to science, however, was the series of discoveries which established photography in the modern sense. The first of these (1834) was the production of photographic images on paper impregnated with silver chloride. The idea of this process was conceived in October, 1833, during a visit to Lake Como in Italy as a result of his attempts to record the scenery on transparent paper in the camera obscura. Upon his return to England he conducted extensive experiments (1834–1835) which led to his first pictures. Meantime others were active in the field, especially the French Daguerre, who

had (1833) made the discovery that a latent image on silver iodide could be developed to a picture by exposure to mercury vapor. A rumor of Daguerre's work caused Talbot to have his process of "photogenic drawing" expounded by Faraday before the Royal Institution on January 25, 1839, and Talbot himself did so before the Royal Society of London on January 31, 1839. A full description of the process was published [Phil. Mag. (3) *14*, 196–211 (1839); Proc. Roy. Soc. London *4*, 120–121, 124–126, 134 (1839)] in the same year.

In the following year (1840) Talbot made another epochal advance by his discovery that the use of silver iodide (rather than silver chloride) enormously increased the sensitivity and speed of formation of the latent image, that it could be developed with gallic acid, and that the resultant image could be fixed with potassium bromide solution [Proc. Roy. Soc. London *4*, 312–316 (1841)]. These operations led to the production of a negative from which any desired number of positive prints could subsequently be made. Talbot himself referred to such prints as "calotypes" (beautiful pictures) but they were also designated as "Talbotypes"; for their invention Talbot received (1842) the Rumford Medal of the Royal Society. His book, "The Pencil of Nature" (1844), became the first publication to be illustrated by photography, this term having been sanctioned through its use by Talbot's friend, Sir John Herschel, in a lecture of March 14, 1839, to the Royal Society.

A decade later (1852) Talbot discovered that after treatment with dichromate, gelatin becomes insoluble upon exposure to light, utilized this characteristic in protecting steel and copper plates from the action of suitable etching solutions, and thus obtained photoetchings suitable for intaglio printing.

Talbot took out patents on all his inventions and vigorously prosecuted all infringements. These severe measures were not helpful to the advancement of photographic science and Talbot was eventually persuaded to open the patents to free public (but not commerical) use.

In addition to the journal publications cited below, an extraordinary wealth of detail regarding Talbot's work can be found in Eder's "History of Photography," English translation (1945) by E. Epstean of the fourth (1932) German edition.

P_2B Phot. J. *87-A*, 3–13 (1947); *74*, 427–433, 435 (1934): P_2B J. Chem. Education *4*, 306–308 (1927); *9*, 1414–1415 (1932): B Nature *133*, 977–978 (1934): B Z. wiss. Phot. *31*, 324–326 (1933): B Phot. J. *77*, 307–313 (1937): B Proc. Roy. Soc. Edinburgh *9*, 512–514 (1878): B Phot. J. *61*, 440–446 (1921): B Phot. J. *64*, 521–524 (1924): B Dict. Natl. Biog. *50*, 339–341 (1898).

DESCARTES, RÉNÉ DUPERRON

Born March 31, 1596, at La Haye, Touraine, France; died Feb. 11, 1650, at Stockholm, Sweden.

This ancient French philosopher, mathematician and physicist whose Latin name of Renatus Cartesius leads to the term Cartesian, was a prodigious traveler but did most of his productive work (1628–1648) in Holland.

Those aspects of this versatile philosopher of most interest to scientists concern his work in mathematics, physics and physiology. He attempted to reduce all science to a kind of applied mathematics or mechanics and has been described as the first modern mathematician. In his "Geometry" (1637) he laid the foundations of analytical geometry. He was the first to attempt a systematic classification of curves and distinguished between "geometric" and "mechanical" varieties, terms which Newton later displaced by "algebraic" and "transcendental." His algebraic work involved the geometric interpretation of negative quantities, led to the concept of continuity and thus to the theory of functions and limits. He first devised the convention of employing the first letters of the alphabet to represent known quantities and the last letters to signify unknowns, and also introduced the use of exponents.

In his books on "The World" and "Principles of Philosophy" Descartes attempted an explanation of the genesis of the physical world and evolved his famous vortex or whirlpool theory. He rejected the corpuscular theory of light and conceived its transmission as pressure from the luminous body, thus preparing the way for the undulatory theory of Huygens. In his "Dioptrics" he published (1637) for the first time the law of refraction of light discovered (1621) but not reported by Snell. He accounted for the formation of multiple rainbows but the explanation of their colors remained for Newton.

His studies on physiology were posthumously published (1662) in "L'Homme" which may be considered the first textbook of physiology.

In 1649 he was invited to Stockholm to instruct the Swedish queen, Christina, in his philosophy. Required by courtesy to accede to her eccentric preference for discussion thrice a week at 5 o'clock in the morning, and harassed by the severity of the northern winter, he developed pneumonia which soon proved fatal. His remains were eventually transferred to France and deposited (1819) in the church of St. Germain du Prés.

The 13 quarto volumes "Oeuvres de Descartes," published 1897–1911 in Paris, include one biographical section (Vol. 12) by C. Adam; there is also in English the work of Elizabeth S. Haldone on "Descartes, His Life and Times," (1905).

B Science Progress *21*, 457–478 (1926–7): B Pop. Sci. Monthly *37*, 833–840 (1890).

BRÜHL, JULIUS WILHELM

Born Feb. 13, 1850, at Warsaw, Poland; died Feb. 5, 1911, at Heidelberg, Germany.

This Polish chemist of Jewish parentage spent most of his professional life in Germany. After study (1868–1870) at Zurich and (1870–1873) in Berlin under A. W. Hofmann in chemistry and G. Quincke in physics he was recommended for an appointment in the newly founded University of Tokyo but preferred to remain in Germany, where his friends included Döbner, Losanitch, Pinner, Tiemann, and Willgerodt. For a six year period (1873–1879) he became assistant to Landolt in the Polytechnikum at Aachen (Aix-la chapelle) (where he began the studies of optical refraction which later dominated his work), meantime obtaining (1875) his doctorate from the University of Göttingen. After a brief period (1879–1884) as professor of chemistry at the Polytechnikum of Lemberg (Lwow) in his native Poland, he was forced by the climate to seek another post and was persuaded by Bunsen to take over at Heidelberg the vacancy left by the departure of Bernthsen to the BASF laboratories at Ludwigshafen. Here he remained (1889–1908) with the title of honorary professor.

Brühl's principal contribution to chemistry was his exhaustive and protracted series of researches on the relations between refractivity and chemical constitution of organic compounds. Subsequent to the pioneering work of Gladstone and Dale in England, Brühl became the chief authority in this branch of science. By 1880 he had recognized that the mode of linking of its constituent atoms was determinative in the optical refraction of organic molecules and thus placed at the disposal of science an important new tool in the establishment of organic structures. He was the first to bring optical evidence to bear on the question of constitution of the benzenoid nucleus. In a lecture to the Royal Institution [Proc. Roy. Institution *18*, 122–135 (1905)] Brühl himself has reviewed the development of what he called "spectrochemistry." Brühl spoke and wrote in German, Polish, Russian, French, English and Italian and continued with the help of Hjelt and Aschan the publication of the organic section of the great chemical treatise of Roscoe and Schorlemmer by two important volumes on the chemistry of 5-membered (1898) and 6-membered (1899) heterocyclic systems.

P_1B Ber. *44*, 3757–3794 (1911) (incl. bibliog.): B Am. Chem. J. *45*, 536–537 (1911): B Nature *85*, 517–518 (1911): B J. chim. phys. *9*, 502 (1911).

HUMMEL, JOHN JAMES

Born Feb. 26, 1850, at Clitheroe, Lancashire, England; died Sept. 13, 1902, in Scotland.

This British pioneer teacher of the art and science of dyeing was of Swiss descent, and received his technical education (1867–1869) at the Zurich Polytechnic under Städeler, Bolley, Wislicenus and Weith. The next decade was absorbed by various industrial connections, first (1869–1875) at the Dalmonach Works of James Black and Company at Alexandria, near Glasgow, Scotland, next (1876) as sub-manager of the Foxhill Bank Print Works at Church, Lancashire, England, then (1877–1878) as a managing partner in the Alexander Print Works, Milngavie, near Glasgow, and finally (1878–1879) at the Nethercoal Dyeworks, Auchterarder, Perthshire, Scotland. This practical experience proved invaluable for at this juncture the Clothworkers Company of the City of London established at Yorkshire College in Leeds a school of dyeing of which Hummel became the head (1880–1902) for the rest of his life.

Yorkshire College of Science was founded in 1874 with three chairs, viz., chemistry, physics and mathematics, geology and mining. To these, departments of biology and of engineering were added in 1876, and when in the following year the teaching of classics, literature and history was added, the institution became Yorkshire College. A decade later (1887) the college was admitted to Victoria University and finally (1904) obtained a separate charter becoming the present University of Leeds.

Hummel's instruction in dyeing began (1880) with about 18 students in primitive accommodations but was so popular and successful that by 1885 it occupied new buildings with special equipment built to Hummel's design. By 1890 its superior training and facilities had become widely recognized and attracted students not only from all parts of the United Kingdom but also from Belgium, Brazil, Canada, France, Germany, India, Japan, and Spain. In this year there was added to its teaching functions special provision for regular systematic research in dyeing and tinctorial science which was actively utilized by Hummel and after his death continued (1903–1916) by A. G. Green and (1916–1926) by A. G. Perkin both of whom had been Hummel's students and (1926–1946) by F. M. Rowe.

Hummel's research achievements were naturally in the chemistry of coloring matters and in problems of dyeing. The former were largely concerned with natural coloring matters containing derivatives of anthraquinone. Of the latter the most outstanding were his development of the process for dyeing and printing basic colors on tannin-

antimony-mordanted cotton and later his work on the chrome mordanting of wool. His principal literary work was the classical "Dyeing of Textile Fabrics" (1885), the first of modern texts in this special field. This went through nine editions in English and was also translated into German, French, Italian, and Japanese. Hummel also wrote many special articles for technical dictionaries and encyclopedias.

B J. Soc. Dyers and Colourists *55*, 14–30 (1939) (incl. bibliog.): B J. Chem. Soc. *83*, 652–654 (1903): B J. Soc. Chem. Ind. *21*, 1176–1177 (1902): B Nature *66*, 520 (1902): B Ber. *35*, 3364 (1902).

SKRAUP, ZDENKO HANS

Born March 3, 1850, at Prague, Bohemia (now Czechoslovakia); died Sept. 10, 1910, at Vienna, Austria.

This distinguished organic chemist received his early education (1866–1871) at the Prague Technische Hochschule, following which he was briefly employed in a Karlsbad stoneware and porcelain factory and at the mint whose director at this period was Schrötter, the discoverer of red phosphorus. In 1873 Skraup entered the University of Vienna where he served as assistant to Rochleder and after the latter's death continued with A. Lieben. Following a not uncommon European practice of the time, he passed his doctoral examinations (1875) at the University of Giessen but continued for some years at Vienna. Subsequently he taught at various places including (1881–1886) the Vienna Handelsakademie and the University of Graz. For two decades (1887–1906) he occupied the chair of chemistry at the Graz Technische Hochschule but spent the last four years (1906–1910) of his life at the University of Vienna as successor to the retired Lieben, who nevertheless outlived Skraup by four years.

Skraup's name is, by contemporary students of organic chemistry, most frequently associated with his discovery [Monatsh. *1*, 316–318 (1880)] and development of the well-known quinoline synthesis which bears his name. Less generally known, however, is his determination of the composition of the pigment known as soluble Berlin blue and his resolution of the relationships between ferrous ferricyanide and ferric ferrocyanide. Rochleder had also interested Skraup in the study of cinchona alkaloids and these researches were extensively pursued. Skraup first established (1878) the empirical formulas of cinchonine and cinchonidine and proved (1880) the structures of cinchoninic acid (quinoline-4-carboxylic acid) and cinchomeronic acid (pyridine-3,4-dicarboxylic acid).

Skraup also pioneered in the field of carbohydrates and with J. König [Monatsh. *22*, 1011–1036 (1901); Ber. *34*, 1115–1118 (1901)] was the first to obtain the disaccharide cellobiose from the polysac-

charide cellulose. He introduced [Monatsh. *26,* 1415–1472 (1905)] a new chemical method for the determination of minimum molecular weights of polysaccharides such as starch, glycogen and cellulose, based upon their reaction with acetic anhydride and hydrogen chloride and subsequent determination of the chlorine content of the product.

P_1B Ber. *43,* 3683–3702 (1910): P_3B Oesterr. Chem. Ztg. *13,* 245–252 (1910) (incl. bibliog.): P_3B J. Chem. Education *20,* 471–473 (1943): P_3B Chem. Ztg. *34,* 1013–1014 (1910): B Ber. *43,* 2782–2783 (1910): B Oesterr. Chem. Ztg. *13,* 228–229 (1910).

Pechmann, Hans von

Born April 1, 1850, at Nürnberg, Germany; died April 19, 1902, at Tübingen, Germany.

This German master of organic synthesis published his first paper at age 29, followed it with a flood of fundamental discoveries for the next two decades, then at age 52 became the victim of self-administered cyanide.

After early college training (1869–1871) at the University of Munich interrupted by a summer semester at Heidelberg (1870), Pechmann completed his professional training at the University of Greifswald in German Pomerania taking his doctorate (1875) under Limpricht with a thesis on the "Sulfonic Acids of p-Toluidine." Following a summer at Geneva and two years (1875–1877) with Sir Edward Frankland in London, he embarked upon his creative career under A. von Baeyer at Munich, serving first in the elementary section of the organic division and later (1885) as assistant professor of analytical chemistry. The last seven years of his life were spent at the University of Tübingen, where as associate professor of general chemistry he succeeded Lothar Meyer.

Pechmann's contributions to the advancement of organic chemistry embraced so wide an area that only a few may be mentioned here. His first paper from the Munich laboratory [Ber. *12,* 2124–2129 (1879)] established the symmetrical structure of anthraquinone, a result simultaneously but quite independently achieved by C. Loring Jackson [Ber. *12,* 1965–1967 (1879)] through a different approach. Together with Carl Duisberg he synthesized [Ber. *16,* 2119–2128 (1883)] β-methylumbelliferone (7-hydroxy-4-methylcoumarin) by condensation of ethylacetoacetate with resorcinol and developed the important general procedure of substituted coumarins still designated as the von Pechmann-Duisberg method. This was closely followed [Ber. *17,* 929–936 (1884)] by a second general coumarin synthesis based upon condensation of phenols with malic acid in the presence of sulfuric acid and commonly known as the von Pechmann coumarin synthesis, the

development of which included the first artificial preparation of daphnetin (7,8-dihydroxycoumarin). He discovered [Ber. *17*, 936–938 (1884)] and named coumalinic acid (2-pyrone-5-carboxylic acid) and made extensive studies of the conversion of such compounds to pyridine derivatives. He was the first [Ber. *17*, 2542–2543 (1884)] to prepare acetonedicarboxylic acid and to make a comprehensive study [Ann. *261*, 151–208 (1890)] of its behavior. He first prepared 1,2-diketones, e.g. biacetyl [Ber. *20*, 3162–3164, 3214 (1887)]. He first prepared methylglyoxal [Ber. *20*, 2541–2544, 3213–3214 (1887)] and diphenyltriketone [Ber. *22*, 852–853 (1889); *23*, 3375–3387 (1890)]. He discovered [Ber. *21*, 2751–2762 (1888)] the class of osotriazoles and simultaneously but independently of Bamberger the formazyl compounds [Ber. *24*, 3255–3260 (1891)]. He was the first [Ber. *27*, 1888–1891 (1894); *28*, 2375 footnote 3 (1895)] to prepare diazomethane and to supply directions [Ber. *28*, 855–861 (1895)] for its preparation from ethyl *N*-nitroso-*N*-methylcarbamate ("nitrosomethylurethane").

P_1B Ber. *36*, 4417–4511 (1903): B Ber. *35*, 1581–1582 (1902): B Z. Angew. Chem. *20*, 1965, 2017–2019 (1907).

WELCH, WILLIAM HENRY

Born April 8, 1850, at Norfolk, Connecticut; died April 30, 1934, at Baltimore, Maryland, age 84.

This dean of American medicine, scholar, educator and administrator was professionally pathologist, bacteriologist and physician, but his influence on medical education and research was profound and his career of intense interest to chemists. Welch was an only child in a family with a deep and wide medical background. His father, four uncles, grandfather and great grandfather were all physicians. After college training (1866–1870) at Yale University, and a year in teaching Latin and Greek at Norwich, N. Y., he seriously embarked on his professional career at the Columbia University College of Physicians and Surgeons (1872–1875) where his M.D. thesis on goitre won first prize. He spent the next three years in Europe including study at Strasbourg with Waldeyer (histology), von Recklinghausen (pathology), Hoppe-Seyler (biochemistry), at Leipzig with Ludwig (physiology) and Wagner (pathology), at Breslau with Cohnheim (pathology) and at Prague, Vienna, Paris and London with other distinguished scientists. Upon his return to America he became (1878–1884) lecturer in pathology at New York City's Bellevue Hospital Medical College and established the first pathological laboratory in the United States.

The last 50 years of his long life divide into three somewhat overlapping phases. The first (1884–1916) and longest began with his appointment as professor of pathology at Johns Hopkins University in

Baltimore, Maryland. Here his researches included the discovery of the gas-producing bacillus (Bacillus welchii) responsible for "gas gangrene" and the development of many other pathological advances. During his tenure the establishment (1889) of the Johns Hopkins Hospital and later (1893) the Johns Hopkins Medical School increasingly diverted him from strictly laboratory duties and utilized his special abilities in the promotion of medical education and general public health activities. Welch himself served (1893–1898) as first dean of the medical school and was instrumental in bringing to the new enterprise Osler in medicine, Halsted in surgery, and Kelly in gynecology, this famous group comprising Sargent's (1905) well-known painting of "The Four Doctors." During this period Welch also founded (1896) the Journal of Experimental Medicine, the first scientific medical journal in the United States and himself served as editor for its first decade. The Rockefeller Institute for Medical Research was organized (1910) in a way largely based on Welch's advice and he long served (1901–1934) as chairman of its board of scientific directors.

The second period of Welch's life (1917–1926) was devoted to the foundation and development of the Johns Hopkins School of Hygiene and Public Health, made possible by the Rockefeller Foundation with Welch as its first director.

In 1926 Welch entered (at age 76) upon a third career in the organization of the Johns Hopkins Institute of the History of Medicine, a project envisaged by him as early as 1888, finally brought to fruition by an endowment from the General Education Board, and since 1929 containing the Welch Memorial Medical Library [see Sci. Monthly *29*, 280–285 (1929)].

Dr. Welch was elected (1895) to the National Academy of Sciences, later (1913–1917) followed Ira Remsen as its president, and was a leader in the foundation of the National Research Council. He served as president of many national professional organizations and was the recipient of many honors from both American and foreign institutions. On his 80th birthday he participated in a celebration unique in the history of tributes paid to a scientist. The speakers included the President of the United States (Herbert Hoover) and the exercises were carried by radio to simultaneous celebrations in other American cities, Europe and Asia. [For a full account see "William Henry Welch at Eighty—A Memorial Record of Celebrations Around the World in His Honor," a volume of 230 pp. edited by V. O. Freeburg and published in 1930]. An authoritative biography by Simon Flexner and James Thomas Flexner was published in 1941 by the Viking Press of New York.

P_1B Biog. Memoirs, Natl. Acad. Sci., U. S. *22*, 215–231 (1943)

(incl. bibliog.): B Science *79*, 529–533 (1934); *52*, 417–453 (1920); P_3B J. Am. Med. Assoc. *102*, 1513–1514 (1934): B Proc. Am. Acad. Arts Sci. *70*, 596–599 (1934–5): B Nature 133, 786 (1934); P_2B Sci. Monthly *23*, 87 (1926); *29*, 280–285 (1929); *30*, 472–473 (1930): *38*, 579–581 (1934): B J. Chem. Education *6*, 1283 (1929): B Am. Dict. Biog. *19*, 621–624 (1936): P_1B Dict. Natl. Biog. *26*, 6–8 (1937).

WESTON, EDWARD

Born May 9, 1850, at Brynn Castle near Oswestry, Shropshire, England (150 miles northwest of London); died Aug. 20, 1936, at Montclair, N. J., age 86.

Weston's parents intended him for medicine but after three years as medical apprentice he abandoned this pursuit for science. Intrigued by the accounts of an American tourist he came (1870) to the United States and after a brief period with a New York manufacturer of photographic chemicals was employed (1871) by the American Nickel Plating Company. Here he invented a method for depositing nickel in such a fashion that it was afterwards malleable. The next year he formed his own electroplating company and built (1872) the first successful dynamo as a substitute for batteries in the commercial electrodeposition of metals. He established (1875) in Newark the first American factory exclusively devoted to the manufacture of dynamos and electrical machinery. During both this early period and a subsequent connection (1881–1888) following consolidation of his firm with the U. S. Electric Lighting Company, lack of methods for precise and convenient electrical measurements compelled him to design and produce new devices for this purpose. This led to his foundation (1888) at Newark, N. J., of what is now the Weston Electric Instrument Corporation.

Weston was a prolific inventor and at the time of his death his 309 patents ranked 8th in the list of living American inventors. He developed and produced (1888) the first moving coil direct reading ammeters and voltmeters. He invented both constantan and manganin (1889), alloys with very low temperature coefficients of electrical resistance. In 1877 he mounted a carbon arc lamp at the corner of Newark's Washington and Market Streets, the first public exhibition of arc lighting in the United States. He was responsible for numerous developments in underground cables, distributing systems, switches, meters and circuit indicators, air pumps, safety fuses and light fixtures. He invented a new filament (Tamadine) for incandescent lamps which constituted their most important advance prior to the arrival of the tungsten filament. Other inventions included a compensated thermocouple instrument for high frequency measurements, the rectifier

bridge for a.c. measurements, and the first commercially practical dry disk photoelectric cell. Weston was also the first (1910) to make use of the synthetic resin Bakelite on a commercial scale in the electrical industry.

In 1892 Weston devised a new type of standard cell employing cadmium and mercury as its fundamental elements. This cell was subsequently (1908) adopted by the International Electric Commission as the official standard of electromotive force, after which Weston opened his patents on it for public use. This cell has at 20° an E.M.F. of 1.0183 international volts and is the most accurate and convenient of all practical electrical standards. [For directions on preparation of such cells by students see J. Chem. Education *18*, 87–89 (1941); for a survey of this and early E.M.F. standards see Trans. Am. Electrochem. Soc. *68*, 133–150 (1935)].

A charter member of the American Institution of Electrical Engineers (founded 1884) he was honored as its president (1888–9) and vice president (1889–1891) and awarded its Lamme medal in 1932. Other recognitions included the Franklin medal (1924) of the Franklin Institute, the Perkin Medal (1915) of the Society of Chemical Industry (American Section), and honorary degrees from McGill (LL.D. 1903), Stevens Institute of Technology (Sc.D. 1904), University of Pennsylvania (LL.D. 1924), and Princeton University (Sc.D. 1910).

P_2B Ind. Eng. Chem. *7*, 243–254 (1915): P_2B Trans. Am. Electrochem. Soc. *70*, 30–32 (1936): P_2B Trans. Am. Electrochem. Soc. *55*, 17–21 (1929): B ibid. *50*, 3–5 (1926): Trans. Am. Inst. Elec. Engrs. *55*, 1049 (1936): B Nature *138*, 496 (1936): B Natl. Cycl. Am. Biog. *5*, 176 (1907): B J. Sci. Instruments *13*, 343 (1936).

Gay-Lussac, Louis Joseph

Born Dec. 6, 1778, at St. Leonard, a small town near Limoges in the ancient province of Limousin, Department Haute-Vienne, France; died May 9, 1850, at Paris.

Gay-Lussac, one of the great chemists of all time, was concerned with physical, inorganic, organic, analytical and industrial chemistry. The reader must understand that the following text can do no more than suggest a few interesting aspects of his career.

For three years (1797–1800) Gay-Lussac studied at the École Polytechnique in Paris; here he became acquainted with Thenard, later his life-long collaborator. Thence he went to the École des Ponts et Chausées as assistant to Berthollet, then just over 50 at the height of his distinguished career. In 1802, without giving up his position with Berthollet, Gay-Lussac rejoined the École Polytechnique, where as assistant professor he sometimes lectured for Fourcroy. In 1809 he

became professor of both chemistry and physics at the Sorbonne, resigning in 1832 for the chair of chemistry at the Jardin des Plantes.

In pursuit of an investigation of terrestrial magnetism, Gay-Lussac at age 26 made two balloon ascensions. The first, made on Aug. 24, 1804, in company with his fellow physicist Biot [see P_3 J. Chem. Education *9*, 1391 (1932)] reached a height of 4000 meters. The second which Gay-Lussac made alone to reduce the weight to be lifted, attained on Sept. 16, 1804, 7016 meters (23,000 feet) [see P_3 J. Chem. Education *12*, 108 (1935)], up to that time the greatest height achieved by man. From samples taken on these ascents, Gay-Lussac established the constancy of composition of the air over this range.

Two fundamental principles discovered by Gay-Lussac are still studied today by every student of chemistry. The first, frequently designated as Gay-Lussac's law, refers to the equal thermal expansion of gases. This principle was first recorded [Ann. chim. (1) *43*, 137–175 (1802)] by Gay-Lussac, although it had been foreshadowed by earlier (1787) but unpublished work of J. A. C. Charles; this fact was meticulously recognized in Gay-Lussac's paper [cf. photograph of page 157 of Gay-Lussac's paper in J. Chem. Education 11, 351 (1934)]. The generalization is, therefore, sometimes called the law of Charles and Gay-Lussac. The second great principle (1808) was the law of combining volumes; i. e., that when substances react in the gaseous state the volumes both of reactants and products stand in the relation of small whole numbers.

The more definitely chemical work of Gay-Lussac, largely in collaboration with Thenard, was very extensive. They established (1809) [Ann. chim. (1) *73*, 229–253 (1910)] the elementary nature of sulfur, determined (1813) that hyposulfites represent a state of oxidation below that of sulfurous acid, and gave the name hyposulfurous acid. Following Courtois' discovery (1811) of iodine, Gay-Lussac and Thenard made a brilliant investigation of its behavior [Ann. chim. (1) *91*, 5–160 (1814)], which included proof of the elementary nature of iodine, and the first preparation of ethyl iodide (from ethyl alcohol and hydriodic acid). With Liebig, who had been introduced to him by their mutual friend von Humboldt, Gay-Lussac prepared hydrogen cyanide (prussic acid) [Ann. chim. (1) *77*, 128–133 (1811)], showed that the CN group behaved as a unit (foreshadowing the Berzelius theory of radicals), obtained and gave the name to cyanogen and first manufactured cyanogen chloride. With Liebig he also carried out a study of fulminic acid [(Poggendorf's) Ann. Physik. *1*, 87–116 (1824)] which included determination of the composition of silver fulminate, now regarded as a sensitive detonator. With Thenard, Gay-Lussac discovered (1808) the amides and later (1810) the peroxides of both sodium and potassium.

Independently of but simultaneously with Döbereiner, Gay-Lussac introduced the use of copper oxide as the active agent in the combustion analysis of organic compounds and first employed copper filings to decompose during the analysis of nitrogen compounds any adventitious oxides of nitrogen; organic chemists also derive from Gay-Lussac [Ann. chim. (2) *46*, 113 (1831)] the name racemic acid [cf. Nature *140*, 22–23 (1937)].

Gay-Lussac may be regarded as the originator of volumetric analysis for in place of the cupellation method universally employed up to his time, he introduced a method for the determination of silver by titration with salt solution. In 1827 he devised a method for the recovery of oxides of nitrogen otherwise lost during the old lead chamber process for the manufacture of sulfuric acid, the industrial version of his apparatus being still designated as the Gay-Lussac tower.

Gay-Lussac became a member of the French Academy of Science in 1806, and was elected (1815) a foreign member of the Royal Society of London at the same time as his friends Biot and von Humboldt.

P_3B J. Chem. Education *11*, 353 (1934); *9*, 1389 (1932); *8*, 1301–1303 (1931): B Ann. Rept. Smithsonian Inst. *31*, 138–172 (1876): B Proc. Roy. Soc. London *5*, 1013–1023 (1843–1850).

HEAVISIDE, OLIVER

Born May 13, 1850, in Camden Town, London; died Feb. 3, 1925, at Torquay, Devon, England.

This self-educated British mathematical physicist and nephew of Sir Charles Wheatstone, in consequence of increasing deafness, withdrew at age 24 from most business and social contacts to his home in Torquay. Here as a recluse he lived in austerity, cooked his own food, suffered from indifferent health, and drew designs for the electrical scientists of the next and subsequent generations. Despite his election (1891) to the Royal Society and his selection (1921) as the first recipient of the distinguished Faraday medal of the Institution of Electrical Engineers, he never attended the meetings of either, and the medal was personally delivered to him at Torquay by the Institution's president. Despite these eccentricities, he sustained an extended scientific correspondence with Fitzgerald, G. F. C. Searle and Sir Oliver Lodge.

Between 1873-1892 he attempted to communicate to appropriate technical journals a large number of important papers; their significance, however, was not appreciated and the rejection of some of them deeply grieved and, to some extent, embittered their author. In 1892 he collected these into two volumes of "Electrical Papers," where their integration facilitated recognition of their merit. The three volumes of his "Electromagnetic Theory" appeared gradually (1893—1899—1912).

Heaviside first recognized (1873) the practicability of duplex and quadruplex telegraphy, was the first (1884) to solve the problem of the high-frequency resistance and inductance of a concentric main, and the first to express the theory of steady rectilinear motion of an electric charge through the ether. From a practical viewpoint his most important work was the creation of the foundation of modern theory of telephonic transmission. He suggested (1902) the probable existence of the region of ionized air considered responsible for the transmission of radio waves around the curvature of the earth now known as the Heaviside (or Kennelly-Heaviside layer).

For consideration of Heaviside as a humorist [J. Franklin Inst. *241*, 435–440 (1946)] and as seen in his books and letters [Technology Review *35*, 214, 234 (1933)] see the indicated references.

P_3B Electrician *94*, 186 (1925): B Electrician *94*, 174–175 (1925): B J. Inst. Elec. Engrs. *60*, 409–410 (1922): Nature *115*, 237–238 (1925): Proc. Am. Acad. Arts Sci. *70*, 544–545 (1934–5): B Dict. Natl. Biog. *1922–30*, 412–414 (1937).

GOLDSCHMIEDT, GUIDO

Born May 29, 1850, in Trieste, Austria; died Aug. 6, 1915, in Vienna, Austria.

This distinguished Austrian organic chemist studied (1869–1871) at the University of Vienna with Redtenbacher and Schneider, obtained his doctorate (1872) at Heidelberg under Bunsen and concluded his professional preparation by two years (1872–1874) at the University of Strasbourg under von Baeyer. After a long (1874–1891) stay in various capacities at the University of Vienna he succeeded Maly at the German University of Prague (1891–1911), subsequently returning to the University of Vienna (1911–1915) to succeed Skraup. Very early in his career (age 26) he visited the United States, travelling as far west as San Francisco and acting as official Austrian representative at the Philadelphia Exposition of 1876.

Goldschmiedt's work in organic chemistry embraced a wide variety of topics including alkaloids, polynuclear hydrocarbons, aldehyde condensations, etc. His greatest contribution is generally regarded as the establishment (1888) of the structure of the opium alkaloid papaverine as 1-(3,4-dimethoxybenzyl)-6,7-dimethoxyisoquinoline. This achievement was noteworthy not only for its own value but also because the compound represented both the first complicated oxygenated alkaloid whose structure was fully elucidated and the first recognition in an alkaloid of the isoquinoline nucleus.

Goldschmiedt was also the first (1875) to show that both oleic and elaidic acids hydrogenate to stearic acid and similarly that erucic and

brassidic acids reduce to behenic acid. Goldschmiedt shares with Fittig and Gebhard the credit for the isolation and recognition (1877) of the polycyclic hydrocarbon fluoranthene. He had isolated from the residues ("Stuppfett") of the distillation of natural mercury ores at Idria in the Italian province of Goriza a new hydrocarbon for which he suggested [Ber. *10*, 2022–2030 (*1877*)] the name "idryl." Concurrently but independently, however, Fittig and Gebhard [Ber. *10*, 2143–2144 (1877); Ann. *193*, 142–160 (1878)] isolated from coal tar a hydrocarbon which they named fluoranthrene (now shortened to fluoranthene) and which eventually proved to be identical with Goldschmiedt's idryl.

P_1B Ber. *49*, 893–932 (1916) (incl. bibliog.): B Chem. Ztg. *39*, 649–650 (1915): B Oesterr. Chem. Ztg. *18*, 145–148 (1915).

BRAUN, (KARL) FERDINAND

Born June 6, 1850, at Fulda, Hesse, Germany; died April 20, 1918, in Brooklyn, N. Y., U. S. A.

This German physicist, inventor of the cathode ray oscillograph now familiar even to laymen because of its indispensability to television receivers, was educated at the Universities of Marburg and Berlin. After attaining his doctorate (1872) under G. H. Quincke with a dissertation on the vibration of elastic rods and strings, he spent several years as Quincke's assistant at Würzburg. He then served successively as professor of physics at Marburg (1876), Strasbourg (1880), the Technische Hochschule at Karlsruhe (1883), and Tübingen (1885), finally returning for the rest of his academic career (1895–1914) to the University of Strasbourg as Director of the Physical Institute. In 1914 he came to America to testify in a patent suit, was interned when the United States entered World War I, and died in Brooklyn seven months before the conflict ended. Eventually his ashes were returned to his native town of Fulda and buried beside those of his parents.

Braun's earlier work included substantial contributions to physical chemistry. He correctly determined (1878) a method for computing electromotive force from thermal data and was the first to study the relation between electromotive potential and pressure in galvanic cells. He discovered (1891) a new capillary electrolytic phenomenon to which he gave the name *electrostenolysis*. He first recognized the relation between the solubility of solids and external pressure and formulated it on a thermodynamic basis.

His later work was largely devoted to electrical aspects of physics. He devised an ingenious, simple and convenient high-tension electrometer still known by his name. He invented (1897) and described [(Wiedemann's) Ann. Physik *60*, 552–559 (1897)] the "Braun tube,"

now both scientifically and popularly known as the cathode ray oscillograph [for special celebration of its 50th anniversary see Naturwissenschaften *35*, 33–38 (1948)]. He succeeded (1904) in producing with ordinary light waves certain effects earlier achieved by Hertz electrically, thus first supplying evidence that light consists of electrical waves. He discovered (1874) unipolar conductivity (rectification) of certain crystals and was first (1899) to apply it in the crystal detector for wireless signals. He pioneered (1902) in the directional transmission and reception of radio communication and devised the so-called closed circuit for radio transmission and reception. In recognition of his services in the development of wireless telegraphy Braun received jointly with G. Marconi the 1909 Nobel Prize in physics.

P_1B Naturwissenschaften *16*, 621–626 (1928): P_3B Elec. Commun. *25*, 319–327 (1948): P_3B Physik. Z. *19*, 537–539 (1918): P_3B Elektrotech. Z. *39*, 269 (1918). B Electrician *81*, 141 (1918).

DUMAS, JEAN BAPTISTE ANDRÉ

Born July 15, 1800, at Alais in the department of the Gard in southern France; died April 11, 1884, at Cannes, in the Maritime Alps, France, age 84.

This great French chemist, investigator, teacher and administrator, after an initial brief apprenticeship to the local apothecary, travelled on foot to Geneva, Switzerland, where he attended the lectures of Pictet (physics), de la Rive (chemistry) and de Candolle (botany). Before the age of 21 he established the presence of iodine in carbonized sponges (then used as a specific against goitre), devised the alcoholic solution of iodine-potsssium iodide now known as tincture of iodine, and with J. L. Prevost engaged in physiological research one result of which was the first recognition of the function of the kidney in the elimination of urea. These and other works of Dumas attracted the attention of Baron A. von Humboldt, who persuaded him to remove (1823) to Paris, where he resided for the rest of his life. Here he was cordially received by such distinguished savants as Ampère, Arago, Biot, Gay-Lussac, La Place, Thenard, Vauquelin and others including the distinguished geologist Alexander Brogniart, whose daughter he married (1826).

Dumas became (1823) repetiteur for Thenard's lectures at the École Polytechnique and also lecturer at the Athenaeum succeeding Robiquet. With T. Olivier and E. Peclet he founded (1828–9) the Central School of Arts and Manufactures of which he was for many years professor of chemistry and in whose fiftieth anniversary celebration he participated. He soon after (1832) succeeded Gay-Lussac at the Sorbonne, shortly (1835) followed Thenard at the École Polytechnique

and only a little later (1839) took the place of Deyeux at the École de Medecine. Thus before the age of forty he filled successively and for some time simultaneously all the important professorships of chemistry in Paris except that of the College of France. Even there he delivered (1836) his famous lectures on the history of chemical philosophy while temporarily supplying in place of Thenard.

Dumas' contributions to science include many still of constant service to chemists. He developed [Ann. chim. (2) *47*, 198–213 (1831)] the well-known Dumas method quantitative determination of nitrogen and a simple procedure [Ann. chim. (2) *33*, 337–391 (1826)] for determination of vapor densities and, therefore, molecular weights of volatile compounds. With Peligot he first (1834) recognized methyl alcohol as one of the products of distillation of wood and gave it the name "wood alcohol." A year later Dumas discovered isoamyl alcohol and subsequently developed the concept of homologous series. With J. S. Stas he first [Ann. *35*, 129–173 (1840)] employed alkali fusion on organic compounds. Dumas discovered that nitriles could be obtained from amides by dehydration with phosphorous pentoxide. He assigned the name propionic acid to the compound previously known as metacetic acid. His studies on the substitution of chlorine for hydrogen in organic molecules, a topic to which his attention was directed by an incident at the Tuileries in which suffocating fumes developed from candles which had been bleached with chlorine, played an important part in the development of the theory of chemical types.

Dumas early (1832) was elected to the Academy of Science, became its perpetual secretary (1868), and was named (1875) to the French Academy to succeed Guizot. He was elected (1840) to the Royal Society of London, was its Copley Medallist in 1843, and delivered (June 17, 1869) at the Royal Institution in London the first of the Faraday Memorial Lectures of the British Chemical Society. This lecture does not appear in any of the Society's periodicals but is given in its special Jubilee Volume (1896), [also in Chemical News *20*, 1–7 (1869)].

P_1B Nature *21*, Special Issue of Feb. 6, 1880, i–xl (Scientific Worthy Series): P_1B Bull. soc. chim. (2) *42*, 549–559 (1884); (2) *45*, 4–64 (1886) (incl. bibliog. of 853 items): B Compt. rend. *98*, 933–945 (1884): P_1B Ber. *17*, Referate 629–760 (1884); *17*, 947–949 (1884): B Proc. Roy. Soc. (London) *37*, x–xxvii (1884) reprinted also in J. Chem. Soc. *47*, 310–323 (1885): B Chemistry and Industry *22*, 333–335 (1944): B Pop. Sci. Monthly *18*, 257–261 (1880): B Proc. Am. Acad. Arts Sci. *19*, 545–556 (1884): P_3B J. Chem. Education *15*, 253–259 (1938).

WÖHLER FRIEDRICH

Born July 31, 1800, at Escherscheim, near Frankfort-on-the-Main, Germany; died September 23, 1882, at Göttingen, Germany, at age 82.

This Nestor of German chemists initially directed his study toward medicine and after beginning (1820) such a course at Marburg transferred the next year to Heidelberg where (1823) he indeed received the degree of doctor of medicine, surgery and obstetrics. However, Leopold Gmelin, whose fame in chemistry had attracted Wöhler to Heidelberg, persuaded him to abandon medicine for chemistry and he spent a year (1823–4) at Stockholm in the laboratory of Berzelius with whom he subsequently maintained a lifelong friendship. Wöhler himself fifty years later published [Ber. *8*, 838–852 (1875)] a charming account of his journey to Sweden and his experiences with Berzelius. His first academic post (1825–1831) was at the Municipal Trade School (Gewerbeschule) at Berlin from which he published [(Pogg.) Ann. Physik *12*, 253–256 (1828)] his epoch-making synthesis of urea. The next four years (1831–1835) he occupied a similar position at Cassel, where he was succeeded (1836) by Bunsen. Most of Wöhler's professional life, however, was spent at Göttingen where succeeding Stromeyer he occupied the chair of chemistry for 46 years (1836–1882) and attracted a stream of students from all over the world. These disciples included such subsequently distinguished American chemists as S. M. Babcock, H. C. Bolton, J. C. Booth, C. F. Chandler, C. A. Goessmann, J. W. Mallet, S. P. Sadtler, E. F. Smith and Ira Remsen [for a complete survey of Wöhler's American students see J. Chem. Education *21*, 158–170 (1944); for an account by E. F. Smith of his experiences as Wöhler's student see J. Chem. Education *5*, 1554–1557 (1928)]. His monument at Göttingen [see P_1 Ber. *23* (Referate), 829–851 (1890)] commemorates the long and distinguished services to chemistry of a scientist who never attended any formal course of chemical instruction.

Wöhler's most important contribution to science was his discovery of the conversion of ammonium cyanate to urea. This demolished the theory that for the formation of organic compounds some "vital force" was necessary and introduced the concept of the rearrangement of atoms within a molecule. [For the complete history of this discovery see Ber. *61-A*, 3–7 (1928) and for its contemporary reception see J. Chem. Education *5*, 1538–1553 (1928)]. Other important organic contributions by Wöhler include his recognition (1832 with Liebig) of the benzoyl radical, his discovery of amygdalin (1837) and hydroquinone (1848). He was, however, equally distinguished as an inor-

ganic chemist for he first isolated metallic aluminum (1827), beryllium (1828), and yttrium (1828), discovered (1832) the dimorphism of arsenious acid and antimony oxide and first (1862) prepared calcium carbide. During his lifetime he published some 320 papers.

Wöhler was primarily concerned with the facts and took little part in the speculative theories which during his lifetime so vigorously engaged the attention of Berzelius, Dumas, Liebig and many others. In one famous instance, however, he published [Ann. *33*, 308–310 (1840)] under the pseudonym of S. C. H. Windler a brief but brilliant satire of the type theory which has become very famous [for translation and discussion see J. Chem. Education *7*, 633–636 (1930)].

In addition to his stay (1823–4) at Stockholm Wöhler later visited France (1833) and England (1835). He served as president of the German Chemical Society and was elected (1854) to the Royal Society of London of which he later (1872) was Copley Medallist.

P_1B Ber. *15*, 3127–3290 (1882) (incl. bibliog.): B Ber. *8*, 989–990 (1875), *13*, 1153–1154 (1880); *15*, 2285–2888 (1882), *65-A*, 88–94 (1932): B Proc. Roy. Soc. (London) *35*, XII–XX (1883): P_1B J. Chem. Education *5*, 1536–1538 (1928): B J. Chem. Soc. *43*, 258–263 (1883): B Nature *26*, 578–579 (1882): B Pop. Sci. Monthly *17*, 539–551 (1880): B Am. Chem. J. *4*, 289–292 (1882–3): B Proc. Am. Acad. Arts Sci. *18*, 463–465 (1882–3).

HENNIGER, ARTHUR RODOLPHE MARIE

Born Aug. 7, 1850, at Oberursel, Nassau, Germany; died Oct. 4, 1884, in Paris at age 34.

Although born in Germany Henniger was a French citizen. At age 17 he entered Wurtz's laboratory, where his exceptional education and manipulative skill quickly attracted attention. He soon became Wurtz's private assistant, then his collaborator. After his medical doctorate (1878) with a dissertation on peptones, Henniger became professor on the medical faculty of the École de Medicine of the University of Paris, sometimes substituting for Wurtz in delivering lectures.

The now well-known conversion of glycerol to allyl alcohol by heating with oxalic acid was worked out by Henniger in collaboration with Tollens [Ann. *156*, 134–174 (1870)]. Subsequently Henniger developed [Ann. chim. (6) 7, 211–233 (1886)] a general method for the partial reduction of polyhydric alcohols by means of formic acid. With Vogt he achieved the first synthesis [Ann. chim. (4) *27*, 129–144 (1872); Bull. soc. chim. (3) *17*, 541–550 (1872); Ann. *165*, 362–376 (1873)] of orcinol (5-methylresorcinol). By most students of organic chemistry, however, his name is associated with the LeBel-Henniger distillation column [Compt. rend. *79*, 480–483 (1874)].

B Bull. soc. chim. (3) *42*, 547–549 (1884): B Ber. *17*, 2812–2813 (1884): B Rév. sci. *34*, 632–633 (1884): B Ann. chim. applicata *1*, 167 (1885).

RICHET, CHARLES ROBERT

Born Aug. 26, 1850, in Paris, France; died Dec. 4, 1935, in Paris, age 85.

This French physiologist, later (1913) recipient of the Nobel Prize in physiology and medicine, was the son of the well-known surgeon, Alfred Richet. The youth studied medicine in Paris receiving M.D. (1877) and Sc.D. in physiology in 1878. He then became associated with the staff of the University of Paris, where for forty years (1887–1927) he served as professor of physiology. He was elected (1899) to the Academy of Medicine and later (1914) to the Academy of Sciences of which latter he subsequently (1933) served as president. Richet was the author of numerous physiological treatises including (1895–1906) a four-volume dictionary of physiology, and for seventeen years (1917–1933) served as co-editor of the French "Journal de Physiologie et Pathologie Génerale."

One of the amazing aspects of his career is the variety of subjects to which he made fundamental contributions. He was physiologist, pathologist, bacteriologist, psychologist, engineer, statistician, poet, dramatist, novelist, playwright and much else. He became deeply interested in psychical investigation and an English translation of his recorded experience in this field appeared in 1923 under the title, "Thirty Years of Psychical Research."

Richet's doctoral thesis (1878) included the first demonstration of the presence of hydrochloric acid in the gastric juice. Later he showed that respiratory exchange is proportional to the surface of the body, thus establishing what is sometimes known as Richet's and Rubner's law. Other physiological topics to which he contributed included studies of the function of brain and nerves and of the production of heat in the animal body. In collaboration with Hericourt, Richet also carried out some of the earliest work on serum therapy, including on December 6, 1890, at the Hotel-Dieu in Paris, the first injection of serum to a human patient.

Richet's most important scientific contribution, however, was his discovery [Compt. rend. soc. biol. *54*, 170–172 (1902)] with P. J. Portier, of the phenomenon of hypersensitivity for which he coined the name "anaphylaxis" but which is now more commonly designated as allergy. While studying the action of the poison of sea anemones, Richet observed that dogs which without any inconvenience had withstood an intravenous injection of a minimal dose were unable a few

days later to survive a second but weaker injection administered in the same way. Since this second treatment was insufficient to kill a fresh animal, the conclusion was drawn that the effect of the first dosage was to produce an increased sensitivity to the action of the second. Subsequently, Richet showed that nearly all substances having this effect are proteins, and established a diagnostic test for certain ones based upon the fact that the hypersensitivity produced is specific for the protein first injected. Richet's work on anaphylaxis was recognized by the award of the Nobel Prize in physiology and medicine for 1913 and forms the basis for our present conception of the causes of hay fever, asthma, certain skin eruptions, and many other allergic conditions.

B Nature *136*, 1017–1018 (1935): P$_3$B Lancet *1935*, II 1380–1381: B Brit. Med. J. *1935*, II 1160–1161: P$_3$B Presse Méd. *43*, II 2043–2045 (1935): B Compt. rend. soc. biol. *120*, 927–929 (1935): P$_3$B Paris Médical *98*, 541 (1935): P$_3$B Riforma méd. *42*, I 621–622 (1926); *52*, I 24, 27 (1936) (Italian).

HOFMEISTER, FRANZ

Born Aug. 30, 1850, at Prague, Austria; died April 26, 1922, at Würzburg, Bavaria, Germany.

This Austro-German physiological chemist, the son of a distinguished Bavarian physician, showed even as a young medical student at the University of Prague a strong inclination toward the biological applications of chemistry. After H. Huppert came to Prague as professor of medical chemistry, Hofmeister served as his first assistant. Upon the establishment of the Prague Institute for Experimental Pharmacology Hofmeister became assistant professor (1883) and quickly associate professor (1885) of this institution. After thus spending 24 years (1872–1896) in Prague he was called to Strasbourg to succeed Hoppe-Seyler in the Chair of Physiological Chemistry, where the second great period (1896–1919) of his life was spent. For his last few years (1918–1922) he held a similar place in the Pathological Institute of the University of Würzburg.

Hofmeister's interests extended over a vast range of physiological and biochemical topics and a bibliography [Ergeb. Physiol. *22*, 39–50 (1923)] comprising both his independent papers and those of and with his numerous students includes 378 entries. His researches on amino acids and proteins led to views on the amide linkages of the latter which subsequently found support in the synthetic work of Emil Fischer and the analytical studies of A. Kossel. Hofmeister was the first [Z. physiol. Chem. *14*, 165–172 (1890); *16*, 187–191 (1892)] to obtain crystalline protein (egg albumin). He made many studies of

animal metabolism and coined the term "hunger diabetes" [Arch. exp. Path. Pharmakol. *26*, 355–370 (1890)] referring to the fact that fasting animals show glycosuria. He anticipated the modern trend toward physicochemical approaches to biology and his work on the effect of salts in coagulation of lyophilic colloids [Arch. exp. Path. Pharmakol. *24*, 247–260 (1888)] is memorialized in the term Hofmeister series.

P_1B Ergeb. Physiol. *22*, 1–31 (1923): B Biochem. Z. *134*, 1–2 (1923): B Arch. exp. Path. Pharmakol. *95*, i–v (1922): B Klin. Wochschr. *1*, 1974–1975 (1922).

GOLDSTEIN, EUGEN

Born Sept. 5, 1850, at Gleiwitz, Upper Silesia, Germany; died Dec. 25, 1930, in Berlin, Germany.

This German physicist was a pioneer in the study of electric discharge through gases at reduced pressure. He studied (1869–1870) at the University of Breslau and subsequently became the first student of von Helmholtz in the newly established physics laboratory at the University of Berlin from which he received his doctorate in 1881. The following fifty years of his life were largely spent in Berlin, first as a physicist with the physical laboratory and later at the Potsdam Observatory. His first scientific paper (1876) was followed by a long series dealing mainly with the production, characteristics and behavior of cathode and anode rays. Goldstein is of most interest to chemists, however, because of his discovery [Sitzungsber. Preuss. Akad. Wiss. *1886*, 691–699] of "canal rays." Twelve years later this paper was reprinted in a more accessible journal [(Wiedemann's) Ann. Physik. *64*, 38–48 (1898)] where by an odd coincidence it immediately followed in the same issue Roentgen's announcement of the discovery of X-rays. Goldstein's original paper together with several subsequent communications on the same topic have now been made easily available under the title "Kanalstrahlen" as No. 231 (1930) of the well-known series collectively known as Ostwald's "Klassiker der Exakten Wissenschaften."

In contrast to the cathode rays established (1869) by J. W. Hittorff following certain earlier but tentative observations by Plücker and subsequently recognized to be streams of electrons leaving the cathode, Goldstein's observed his "canal rays" to move in the opposite direction. By using a cathode perforated with small holes some of the rays passed through these orifices and produced luminous streamers which suggested canals. Goldstein noted that this radiation was not appreciable influenced by magnetic forces able to produce large deflections of the cathode rays, but twelve years later (1898) Wien discovered that under suitable magnetic conditions they were deflected in a direction

opposite to that of cathode rays and hence carried positive charges. Subsequently the term canal rays was gradually replaced by that of "positive rays" suggested by J. J. Thomson. Subsequent studies of positive rays by W. Wien, J. J. Thomson, and especially F. W. Aston led to the development of the mass spectrograph with which the ratio e/m of charge to mass can be measured with great accuracy. Since such determinations led to the discovery of isotopes, Goldstein's initial discovery of "canal rays" may be considered the foundation of an important aspect of modern chemical physics.

P_1B Naturwissenschaften *8*, frontispiece to Heft 36, 717–725 (1920) (incl. bibliog.): P_3B Physik. Z. *31*, 873–876 (1930): B Naturwissenschaften *18*, 773–776 (1930): B Forschungen u. Fortschr. *6*, 330 (1930); 7, 46 (1931): B Verhandl. deut. physik. Ges. *12* (1931).

LASSAIGNE, JEAN-LOUIS

Born Sept. 22, 1800, in Paris, France; died March 18, 1859, in Paris.

This obscure French chemist studied under Vauquelin, became professor of industrial chemistry at a trade school in Paris, then professor of chemistry (1828) at the Alfort Veterinary School and finally (1854) chemist for the Departement de la Seine. Although the Royal Society Catalogue of Scientific papers indicates his publication of nearly 200 papers, recorded information on his career is conspicuously absent.

His name, however, is well known to organic chemists because of his discovery of a method for the detection of nitrogen in organic compounds, variations of whose fundamental principle are still in constant use. More than 100 years ago Lassaigne discovered [Compt. rend. *16*, 387–390 (1843); Ann. *48*, 367–368 (1843); J. prakt. Chem. (1) *29*, 148–152 (1843)] that upon fusion with metallic potassium organic matter containing nitrogen gave potassium cyanide, the detection of which by simple conversion to ferric ferrocyanide (Prussian Blue) thus indicated the original presence of nitrogen in the organic sample. The use of metallic sodium in place of potassium appears to have been introduced by O. Jacobsen [Ber. *12*, 2318 (1879)]. Various other minor changes in the method have been reviewed by S. H. Tucker [J. Chem. Education *22*, 212–215 (1945)] but the essence of the test stands substantially unchanged.

LECHATELIER, HENRY LOUIS

Born Oct. 8, 1850, in Paris; died Sept. 17, 1936, at Miribel-les-Echelles near Grenoble, in the Dept. Isère, southeastern France, at age 86.

LeChatelier, eldest of six children, and whose father maintained close friendship with Dumas, Chevreul, Siemens, and especially Sainte-

Claire Deville, entered (1869) the École Polytechnique. His studies were interrupted by the siege of Paris but after finishing (1871–3) at the École des Mines he spent several years in government engineering work. At age 27 (1877) he returned to the School of Mines in the chair of general chemistry which a decade later (1887) he exchanged for that of industrial chemistry and metallurgy retaining this post until 1919. From 1897–1907 he also served as professor of inorganic chemistry at the College de France succeeding Schutzenberger, and from 1907 occupied the chair of general chemistry at the Sorbonne succeeding Moissan.

LeChatelier, a prolific writer with interests in many fields, published over 500 articles and books. An initial interest in the setting of cement developed further in his doctoral thesis (1887), his first book (1903) and its subsequent English translation (1905) has formed the basis of present knowledge in this field. Confronted in these studies with the necessity for improving on contemporary methods of high temperature measurement, he devised the platinum vs. 90 platinum/10 rhodium thermocouple which today comprises the international standard. His treatise (1900) on measurement of high temperatures, especially as translated and revised by G. K. Burgess (1912) comprised a landmark. He made fundamental studies of alloys both with respect to chemical constitution (including intermetallic compounds, solid solutions, and allotropic modifications) and physical structure. He devised numerous new methods and instruments including a revolutionary form of metallographic microscope. He founded (1904) the Revue de Metallurgie and served (1904–1910) as its first editor. Earlier concern with explosions of mine gases interested him in extensive studies of chemical equilibria which culminated in his expression of LeChatelier's Principle (i. e., that a system tends to change so as to minimize the effects of an external disturbance) by which he is best known to students of chemistry.

For LeChatelier's public service and impressive honors more extended treatments must be consulted. He was elected (1907) to the French Academy of Science succeeding Moissan and (1913) a foreign member of the Royal Society of London.

P_1B Obit. Notices, Fellows Royal Society (London) *2*, 251–259 (1938): P_1B J. Chem. Soc. *1938*, 139–150: P_1B J. Chem. Education *7*, 2537–2539 (1930): P_1B Rév. mét., Special No., 1–160 (Jan. 1937) (incl. bibliog. and many portraits): B Bull. soc. chim. (5) *4*, 1557–1611 (1937) (incl. bibliog.): B Ber. *69–A*, 228 (1936); *72–A*, 122–127 (1939): P_2B J. Chem. Education *8*, 442–461 (1931): P_3B Bull. Am. Ceram. Soc. *16*, 155–163 (1937); bibliog. in Ceram. Abstracts *16*, 316–322 (1937): P_3 J. Chem. Education *11*, 510 (1934); *14*, 555–560 (1937); *15*,

289–290 (1938): P_3B Naturwissenschaften *24*, 769–770 (1936): B Chimie et Industrie *36*, 669–672 (1936): B Compt. rend. *203*, 551–552 (1936): B Nature *138*, 711–712 (1936): B Mineralog. Mag. *25*, 296 (1938–40): B J. Iron and Steel Inst. *134*, (2) 637P–640P (1936): B Zentr. Mineral. Geol. Abt. A, *1937*, 57–59: P_3B Chem. Weekblad *33*, 775–776 (1936) (Dutch): B Roczniki Chem. *17*, 53–60 (1937) (Polish).

DOEBNER, OSKAR GUSTAV

Born Nov. 20, 1850, at Meiningen, Thüringen, Germany; died March 28, 1907, at Marseille, France, during a vacation trip.

This pioneer of organic synthesis, one of seven children, was at first uncertain of which field of science he would pursue. After completing the Gymnasium of his native town, he began (1869) at Jena the study of botany. This was continued (1869–1870) in Munich and accompanied both by zoology and by inorganic chemistry under Liebig. After active service in the Franco-Prussian War he resumed his studies by enrolling at Leipzig where he attended lectures by Leuckart in zoology, by Credner in geology, and by Kolbe in organic chemistry. These experiences seemed to settle his doubts in favor of organic chemistry and he next (1872–1873) obtained his doctorate at Tübingen with a dissertation on derivatives of biphenyl under Fittig.

Doebner then became (1874–1875) an assistant to Otto at Braunschweig, and afterward (1875–1879) occupied a similar position with A. W. Hofmann at Berlin, where (1879–1884) he also served as privat dozent. For some 23 years he taught at the University of Halle, first (1884–1899) as assistant professor, then (1899–1907) as associate professor of chemistry and pharmacy.

Doebner's first important contribution to chemistry was the discovery [Ber. *11*, 1236–1241, 2274–2277 (1878)] of the condensation of benzotrichloride with dimethylaniline to give the important dyestuff Malachite Green (E. C. I. No. 657). It should be noted, however, that the preparation of this dye from benzaldehyde and dimethylaniline followed by oxidation of the resultant leuco compound had been noted by Otto Fischer [Ber. *10*, 950–952, 1624–1625 (1877)] in the preceding year. The analogous but simpler dye known as Doebner's violet was a later development [Ber. *15*, 234–239 (1882)] and never became a commercial material.

His second important development, carried out in collaboration with W. von Miller at Berlin, was the general synthesis of α-substituted quinolines now generally known as the Döbner-Miller reaction. By this means these workers achieved [Ber. *14*, 2812–2817 (1881)] the synthesis of quinaldine (2-methylquinoline) and subsequently elaborated the method in a long series of publications. A variant in which

aromatic primary amines condense with aldehydes and pyruvic acid to yield derivatives of quinoline-4-carboxylic acid (cinchoninic acid) is known as Doebner's pyruvic acid method [Ann. *242*, 265–300 (1887)]. Many other variations and extensions of the Doebner-Miller reaction have since been studied.

Other advances due to Doebner include his discovery of the permanganate oxidation of phenol to mesotartaric and oxalic acids [Ber. *24*, 1753–1757 (1891)], his synthesis of α-alkyl-β-naphthocinchoninic acids by condensation of aldehydes with pyruvic acid and β-naphthylamine and its application to the characterization of aldehydes [Ber. *27*, 352–354, 2020–2030 (1894)] especially those from essential oils, his proof of the structure [Ber. *23*, 2372–2377 (1890); *27*, 344–351 (1894)] and subsequent achievement of the synthesis [Ber. *33*, 2140–2142 (1900)] of sorbic acid (hexadien-2,4-oic acid), and his synthesis [Ber. *35*, 1147–1148 (1902)] of muconic acid (hexadien-2,4-dioic acid 1,6).

B Ber. *40*, 1485, 5131–5140 (1907) (incl. bibliog.); P_3B Z. Angew. Chem. *20*, 736 (1907).

HESS, GERMAIN HENRI

Born Aug. 7, 1802, in Geneva, Switzerland; died Dec. 12, 1850 (New Style) in St. Petersburgh.

Hess, one of the foremost physical chemists of Russia during the early nineteenth century, became (1832) professor of chemistry and inspector of mining cadet corps, one of the founders (1828) of the Technological Institute of St. Petersburgh, and a member (1834) of the Russian Academy of Science. His textbook, "Fundamentals of Pure Chemistry," (1831) passed through seven editions (last in 1849). With the collaboration of P. G. Sobolevskij, S. J. Nečaev and M. S. Soloviev he devised a rational Russian chemical nomenclature still employed. Internationally he is best known for his work (1836–1841) on heats of chemical reactions, compactly assembled (1890) by W. Ostwald as the ninth of his famous series, "Classics of the Exact Sciences," and familiar to chemists as Hess' law of constant heat summation.

P_3B J. Chem. Education *11*, 228 (1934).

GOODYEAR, CHARLES

Born Dec. 29, 1800, at New Haven, Connecticut; died July 1, 1860, in New York City.

This American discoverer of the vulcanization of rubber was the son of a New Haven hardware manufacturer and merchant. At age 17 he was placed with the hardware firm of Rogers Brothers in Phila-

delphia to learn this trade and subsequent y went into partnership with his father at Naugatuck, Connecticut. In 1824 he married and eventually acquired a family of six including two sons who later made independent names for themselves; the older, Charles Goodyear, Jr. (Jan. 1, 1833–May 22, 1896) founded the Goodyear Shoe Machinery Company which became one of the initial components of the present United Shoe Machinery Corporation; the younger, William Henry Goodyear (April 21, 1846–Feb. 19, 1923) was of artistic temperament, became a well-known archeological and architectural scholar and for 33 years (1890–1923) was head of the department of fine arts of the Brooklyn Institute of Arts and Sciences.

In 1834 while on a business trip to New York Goodyear chanced to notice in a display of the Roxbury India Rubber Company a rubber life preserver whose mechanical valve he felt that he could improve. Struck by the ingenuity displayed in this respect, the agent confided to him the difficulties faced by the company in attempting to overcome the tendency of their rubber products to soften in summer and to become brittle in winter. Despite his lack of any prior experience with or chemical knowledge of rubber, Goodyear forthwith threw himself with fanatical devotion into a protracted attempt to solve this problem.

After several years of fruitless endeavor he employed early in 1838 a Nathaniel Hayward (1808–1865) who during prior experience with a rubber company had found that by mixing raw rubber with sulfur and exposing the surface to sunlight, the objectionable adhesiveness of the surface was permanently removed. This solarizing process did not, however, have any influence upon the unfortunate temperature characteristics and could be utilized only on thin surfaces. Recognizing an advance, however, Goodyear persuaded Hayward to patent his method and then bought the patent for $200. Early in 1839 at his house in Woburn, Mass., while conferring with a group regarding this mixture of sulfur and gum rubber, Goodyear accidentally dropped his sample on a hot stove, where to his astonishment the material failed to melt. This discovery of what he designated as vulcanization of rubber eventually culminated on June 15, 1844, in the issuance of U. S. Patent 3,633. An attack on the validity of this patent by one Horace H. Day led to a famous trial at Trenton, N. J., in which the astute Daniel Webster, for the highest fee ($25,000) ever paid an American attorney up to that time, defended Goodyear against Rufus Choate representing Mr. Day. A decision in favor of Goodyear was handed down on Sept. 28, 1852.

Goodyear published (1853–1855) a two-volume treatise entitled, "Gum-elastic and its varieties, with a detailed account of its applications and uses and of the discovery of vulcanization." It was bound

in India rubber and a few copies were actually printed on rubber tissue. A complete facsimile reproduction of both volumes of this rare work, together with a similar copy of Thomas Hancock's "Caoutchouc or India-Rubber Manufacture in England" (1857), the three works together comprising one bound volume of some 925 pages, was distributed as a souvenir of the Centennial celebration of the discovery of the vulcanization of rubber at the 100th National Meeting of the American Chemical Society in Boston, Mass., in 1939. [For a further account of this observance see Ind. Eng. Chem. *31*, 1189–1217 (1939) and India Rubber World *101*, No. 1, 89–96 (1939)].

P_3B Ind. Eng. Chem. *31*, 1191–1192 (1939): P_3B J. Chem. Education *7*, 1788–1801 (1930): P_3B India Rubber World *101*, No. 1, 48–49 (1939): P_1B Pop. Sci. Monthly *53*, 697–700 (1898): B Gummi Ztg. *38*, 173–174 (1923): B Dict. Am. Biog. *7*, 413–415 (1931): P_1B Natl. Cyclop. Am. Biog. *3*, 86 (1893).

Proceedings of the American Academy of Arts and Sciences

VOL. 78, NO. 2, P. 37–132 — FEBRUARY, 1950

WINTER NUMBER

American Academy of Arts and Sciences

OFFICERS AND COMMITTEES FOR 1949-1950

President
HOWARD MUMFORD JONES

Vice-Presidents

Class I
JEROME C. HUNSAKER

Class II
IRVING W. BAILEY

Class III
ROBERT B. STEWART

Class IV
WILLIAM A. JACKSON

Secretary
JOHN W. M. BUNKER

Treasurer
HORACE S. FORD

Librarian
ERNEST H. HUNTRESS

Editor
TAYLOR STARCK

Executive Officer
RALPH W. BURHOE

Councillors

Class I		Class II
PHILIP FRANKLIN	*Terms expire 1950*	FREDERICK K. MORRIS
JOSEPH H. KEENAN	*Terms expire 1951*	PAUL C. MANGELSDORF
ISADORE AMDUR	*Terms expire 1952*	ARLIE V. BOCK
EDWIN H. LAND	*Terms expire 1953*	FRANCIS O. SCHMITT
Class III		**Class IV**
CHARLES E. WYZANSKI, JR.	*Terms expire 1950*	JOHN G. BEEBE-CENTER
HARVEY H. BUNDY	*Terms expire 1951*	WILLIAM G. CONSTABLE
KEYES DEW. METCALF	*Terms expire 1952*	HENRY R. VIETS
W. RUPERT MACLAURIN	*Terms expire 1953*	GEORGE W. SHERBURN

The House Committee
CHESTER M. ALTER, *Chairman*

CHARLES H. TAYLOR — JOHN B. WILBUR

The Committee on Membership
HOWARD M. JONES, *Chairman, ex officio*

Class I		Class II
GEORGE SCATCHARD	*Terms expire 1950*	RALPH H. WETMORE
KENNETH T. BAINBRIDGE	*Terms expire 1951*	SAMUEL A. LEVINE
Class III		**Class IV**
ARTHUR N. HOLCOMBE	*Terms expire 1950*	W. FREEMAN TWADDELL
ERWIN D. CANHAM	*Terms expire 1951*	WILBUR K. JORDAN

The Committee on Meetings

Howard M. Jones, *Chairman, ex officio*
John W. M. Bunker, *Secretary, ex officio*

Class I
Henry B. Phillips
Jerome C. Hunsaker, *ex officio*

Class II
George Wald
Irving W. Bailey, *ex officio*

Class III
Erwin H. Schell
Robert B. Stewart, *ex officio*

Class IV
William Emerson
William A. Jackson, *ex officio*

The Committee on Finance

Horace S. Ford, *Chairman, ex officio*

Ralph E. Freeman
Jerome C. Hunsaker
Henry P. Kendall
Henry L. Shattuck

The Auditing Committee

Thomas H. Sanders
Donald S. Tucker

The Committee on Publication

Taylor Starck, *Chairman, ex officio*

Ernest H. Huntress
Kenneth B. Murdock
Kenneth V. Thimann
Thomas North Whitehead

The Permanent Science Fund Committee

Hudson Hoagland, *Chairman*

Gustavus J. Esselen
A. Baird Hastings
Edward L. Moreland
Frederick K. Morris
Talcott Parsons
Julius A. Stratton

The Rumford Committee

Harlow Shapley, *Chairman*

Percy W. Bridgman
Arthur C. Hardy
George R. Harrison
Joseph H. Keenan
Edwin H. Land
Francis O. Schmitt

The C. M. Warren Committee

Frederick G. Keyes, *Chairman*

Edwin J. Cohn
Louis F. Fieser
Charles A. Kraus
Eugene M. Landis
Avery A. Morton
Walter C. Schumb

The Amory Prize Committee

Edwin B. Wilson, *Chairman*

William B. Castle
Roy G. Hoskins
Gregory Pincus
George W. Thorn
George B. Wislocki
S. Burt Wolbach

LIST

OF THE

FELLOWS AND FOREIGN HONORARY MEMBERS

(Corrected to January 1, 1950)

FELLOWS—866

(Number limited to one thousand)

The year of election is indicated in the left margin, the century being omitted; thus 21 means 1921, 92 means 1892. When a Fellow resigned and was re-elected, the year of re-election is indicated in the ordinary way, the year of election is enclosed in square brackets. The year of election of an Associate, now a Fellow, is indicated by round brackets.

CLASS I—Mathematical and Physical Sciences—246

Section 1—*Mathematics and Astronomy*—50

21 Charles Greeley Abbot........................Washington, D. C.
32 Clarence Raymond Adams........................Providence, R. I.
12 George Russell Agassiz........................Dedham
47 Howard Hathaway Aiken........................Cambridge
17 Raymond Clare Archibald........................Providence, R. I.
46 James Gilbert Baker........................Orinda, Cal.
46 John Landes Barnes........................Pacific Palisades, Cal.
32 Albert Arnold Bennett........................Providence, R. I.
45 Garrett Birkhoff........................Cambridge
35 Gilbert Ames Bliss........................Flossmore, Ill.
39 Bart Jan Bok........................Lexington
46 Subrahmanyan Chandrasekhar........................Williams Bay, Wis.
13 Julian Lowell Coolidge........................Cambridge
15 Leonard Eugene Dickson........................Joliet, Ill.
33 Jesse Douglas........................Brooklyn, N. Y.
38 John Charles Duncan........................Wellesley
34 Griffith Conrad Evans........................Berkeley, Cal.
30 Philip Franklin........................Belmont
32 Einar Hille........................New Haven, Conn.
13 Edward Vermilye Huntington........................Cambridge
49 Witold Hurewicz........................Cambridge
38 E[lvin] Morton Jellinek........................Fort Worth, Tex.
49 Gerard Peter Kuiper........................Williams Bay, Wis.
15 Carl Otto Lampland........................Flagstaff, Ariz.
45 Norman Levinson........................Belmont

25 Willem Jacob Luyten..........................Minneapolis, Minn.
44 Saunders MacLane..........................Chicago, Ill.
48 William Ted Martin..........................Belmont
34 Donald Howard Menzel..........................Cambridge
19 George Abram Miller..........................Urbana, Ill.
23 Samuel Alfred Mitchell..........................University, Va.
29 Marston Morse..........................Princeton, N. J.
19 Forest Ray Moulton..........................Washington, D. C.
44 John von Neumann..........................Princeton, N. J.
43 Cecilia Payne-Gaposchkin..........................Lexington
18 Henry Bayard Phillips..........................Lincoln
96 Charles Lane Poor..........................New York, N. Y.
02 Henry Norris Russell..........................Princeton, N. J.
20 Harlow Shapley..........................Cambridge
09 Vesto Melvin Slipher..........................Flagstaff, Ariz.
19 Virgil Snyder..........................Ithaca, N. Y.
21 Joel Stebbins..........................Mt. Hamilton, Cal.
27 Harlan True Stetson..........................Needham
30 Dirk Jan Struik..........................Belmont
42 Otto Struve..........................Williams Bay, Wis.
23 Oswald Veblen..........................Princeton, N. J.
29 Joseph Leonard Walsh..........................Cambridge
41 Fred Lawrence Whipple..........................Cambridge
32 David Vernon Widder..........................Arlington
48 Oscar Zariski..........................Cambridge

CLASS I, SECTION 2—*Physics*—68

28 Adelbert Ames, Jr..........................Hanover, N. H.
37 Kenneth Tompkins Bainbridge..........................Cambridge
21 Samuel Jackson Barnett..........................Pasadena, Cal.
49 Jesse Wakefield Beams..........................Charlottesville, Va.
42 Francis Birch..........................Cambridge
12 Percy Williams Bridgman..........................Cambridge
39 Lyman James Briggs..........................Washington, D. C.
26 Walter Guyton Cady..........................Middletown, Conn.
03 George Ashley Campbell..........................Upper Montclair, N. J.
21 Leslie Lyle Campbell..........................Lexington, Va.
16 Emory Leon Chaffee..........................Belmont
28 Arthur Holly Compton..........................St. Louis, Mo.
31 Karl Taylor Compton..........................Cambridge
12 Daniel Frost Comstock..........................Lincoln
47 Edward Uhler Condon..........................Washington, D. C.
15 William David Coolidge..........................Schenectady, N. Y.
34 Franzo Hazlett Crawford..........................Williamstown
13 Henry Crew..........................Evanston, Ill.
11 Harvey Nathaniel Davis..........................Hoboken, N. J.

29 Clinton Joseph Davisson........................Charlottesville, Va.
12 Arthur Louis Day........................Bethesda, Md.
46 Lee Alvin Du Bridge........................Pasadena, Cal.
01 Alexander Wilmer Duff........................Worcester
45 Robley Dunglison Evans........................Belmont
09 Arthur Woolsey Ewell........................Worcester
39 Harry Edward Farnsworth........................Providence, R. I.
49 James Brown Fisk........................Basking Ridge, N. J.
49 Nathaniel Herman Frank........................Cambridge
43 Philipp Frank........................Cambridge
49 Wendell Hinkle Furry........................Cambridge
29 Arthur Cobb Hardy........................Wellesley
31 *George Russell Harrison*........................Belmont
14 John Charles Hubbard........................Washington, D. C.
17 Gordon Ferrie Hull........................Hanover, N. H.
40 Frederick Vinton Hunt........................Belmont
22 Edwin Crawford Kemble........................Cambridge
44 Ronold Wyeth Percival King........................Winchester
43 Edwin Herbert Land........................Cambridge
37 Ernest Orlando Lawrence........................Berkeley, Cal.
31 Robert Bruce Lindsay........................Providence, R. I.
01 Theodore Lyman........................Brookline
34 Louis Williams McKeehan........................Washington, D. C.
14 Robert Andrews Millikan........................Pasadena, Cal.
34 Harry Rowe Mimno........................Lexington
34 Philip McCord Morse........................Cambridge
49 Hans Mueller........................Cambridge
31 Otto Oldenberg........................Cambridge
40 J. Robert Oppenheimer........................Princeton, N. J.
34 Leigh Page........................New Haven, Conn.
07 George Washington Pierce........................Cambridge
41 Isidor Isaac Rabi........................New York, N. Y.
48 Bruno Benedetto Rossi........................Winchester
48 Julian Seymour Schwinger........................Boston
27 John Clarke Slater........................Cambridge
37 George Walter Stewart........................Iowa City, Ia.
43 Donald Charles Stockbarger........................Belmont
46 Julius Adams Stratton........................Belmont
37 Jabez Curry Street........................Belmont
28 Manuel Sandoval Vallarta........................Mexico, D. F.
35 Robert Jemison Van de Graaff........................Belmont
34 John Hasbrouck Van Vleck........................Cambridge
35 Bertram Eugene Warren........................Arlington
18 David Locke Webster........................Palo Alto, Cal.
48 Victor Frederick Weisskopf........................Cambridge
11 Edwin Bidwell Wilson........................Brookline

13 Robert Williams Wood..............................Baltimore, Md.
49 Jerrold Reinach Zacharias..............................Cambridge
17 John Zeleny..............................New Haven, Conn.

CLASS I, SECTION 3—*Chemistry*—66

26 Roger Adams..............................Urbana, Ill.
44 Isadore Amdur..............................Cambridge
45 Eric Glendinning Ball..............................Newton Highlands
13 Wilder Dwight Bancroft..............................Ithaca, N. Y.
46 Paul Doughty Bartlett..............................Weston
07 Gregory Paul Baxter..............................Cambridge
29 James Alexander Beattie..............................Belmont
19 Arthur Alphonso Blanchard..............................Brookline
14 Marston Taylor Bogert..............................New York, N. Y.
36 Harold Simmons Booth..............................Cleveland, O.
49 William Clouser Boyd..............................Boston
38 Emile Monnin Chamot..............................Ithaca, N. Y.
42 Samuel Cornette Collins..............................Belmont
24 James Bryant Conant..............................Cambridge
45 Arthur Clay Cope..............................Belmont
48 Carl Ferdinand Cori..............................St. Louis, Mo.
48 Charles DuBois Coryell..............................Lexington
47 Paul Clifford Cross..............................Seattle, Wash.
37 John Tileston Edsall..............................Dedham
37 Gustavus John Esselen..............................Swampscott
33 Louis Frederick Fieser..............................Belmont
35 Louis Harris..............................Belmont
36 Albert Baird Hastings..............................Brookline
38 Robert Casad Hockett..............................Concord
36 Ernest Hamlin Huntress..............................Melrose Highlands
19 Frederick George Keyes..............................Cambridge
49 John Gamble Kirkwood..............................Pasadena, Cal.
33 George Bogdan Kistiakowsky..............................Cambridge
15 Charles August Kraus..............................Providence, R. I.
14 Arthur Becket Lamb..............................Brookline
18 Irving Langmuir..............................Schenectady, N. Y.
15 Warren Kendall Lewis..............................Newton
49 James Joseph Lingane..............................Cambridge
49 Fritz Albert Lipmann..............................Boston
23 Duncan Arthur MacInnes..............................New York, N. Y.
32 Kenneth Lamartine Mark..............................Boston
41 Charles Edward Kenneth Mees..............................Rochester, N. Y.
35 Nicholas Athanasius Milas..............................Belmont
36 Avery Adrian Morton..............................Watertown
19 Edward Mueller..............................Cambridge

49 John Howard Northrop..............................Berkeley, Cal.
31 William Albert Noyes, Jr...........................Rochester, N. Y.
45 John Lawrence Oncley..............................Newtonville
49 Lars Onsager.................................New Haven, Conn.
44 Linus Carl Pauling...............................Pasadena, Cal.
39 Clifford Burrough Purves.........................Montreal, Can.
49 Eugene Rochow....................................Cambridge
14 Martin André Rosanoff..........................Mt. Lebanon, Pa.
28 George Scatchard.................................Cambridge
32 Walter Cecil Schumb.............................East Milton
15 Miles Standish Sherrill...........................Brookline
20 Harry Monmouth Smith..............................Brookline
34 Leighton Bruerton Smith...........................Beverly
49 Wendell Meredith Stanley.........................Berkeley, Cal.
47 Clark Conkling Stephenson........................Cambridge
46 Walter Hugo Stockmayer...........................Weston
49 James Batcheller Sumner..........................Ithaca, N. Y.
43 Hugh Stott Taylor...............................Princeton, N. J.
38 Harold Clayton Urey.............................Chicago, Ill.
48 Vincent du Vigneaud.............................New York, N. Y.
41 Harry Boyer Weiser..............................Houston, Tex.
11 Willis Rodney Whitney.........................Schenectady, N. Y.
19 Robert Seaton Williams............................Belmont
44 Edgar Bright Wilson, Jr...........................Cambridge
48 Robert Burns Woodward............................Cambridge
41 Ralph Chillingworth Young.........................Arlington

Class I, Section 4—*Technology and Engineering*—62

06 Comfort Avery Adams.........................Philadelphia, Pa.
42 Wilmer Lanier Barrow..................Garden City, L. I., N. Y.
33 Harold Kilbrith Barrows..........................Winchester
31 Charles Harold Berry..............................Belmont
41 Edward Lindley Bowles............................Wellesley
25 Vannevar Bush..............................Washington, D. C.
49 Arthur Casagrande................................Cambridge
48 John Chipman.....................................Winchester
49 Edward Lull Cochrane.............................Cambridge
45 Hardy Cross...................................New Haven, Conn.
34 Otto Gustav Colbiornsen Dahl......................Boston
34 Chester Laurens Dawes............................Cambridge
34 Jacob Pieter Den Hartog.......................Wellesley Hills
43 Bradley Dewey....................................Cambridge
20 Theodore Harwood Dillon......................Washington, D. C.
41 Charles Stark Draper..............................Newton

22 Gano Dunn....................................New York, N. Y.
21 William Frederick Durand..........................Palo Alto, Cal.
46 Howard Wilson Emmons..............................Sudbury
27 Gordon Maskew Fair................................Cambridge
48 Ivan Alexander Getting.............................Belmont
32 Glennon Gilboy....................................Lincoln
48 Edwin Richard Gilliland...........................Arlington
32 Albert Haertlein..................................Watertown
40 Harold Locke Hazen................................Belmont
44 Arthur Robert von Hippel..........................Weston
36 Murray Philip Horwood.............................Cambridge
48 Hoyt Clarke Hottel................................Winchester
34 Jerome Clarke Hunsaker............................Boston
49 Arthur Thomas Ippen...............................Cambridge
23 James Robertson Jack..............................Watertown
11 Dugald Caleb Jackson..............................Cambridge
01 Lewis Jerome Johnson..............................Cambridge
48 Theodore von Kármán...............................Azusa, Cal.
37 Joseph Henry Keenan...............................Belmont
23 William Henry Lawrence............................Jamaica Plain
38 John Moyes Lessells...............................Brookline
48 William Henry McAdams.............................Newton
37 Charles Winters MacGregor.........................Belmont
12 Lionel Simeon Marks...............................Cambridge
44 Richard von Mises.................................Cambridge
34 Edward Leyburn Moreland...........................Wellesley
49 John Torrey Norton................................Cambridge
20 Frederick Law Olmsted.............................Elkton, Md.
28 Langdon Pearse....................................Chicago, Ill.
13 Harold Pender.....................................Wynnewood, Pa.
30 Greenleaf Whittier Pickard........................Newton Center
41 Reinhold Rüdenberg................................Belmont
48 Thomas Kilgore Sherwood...........................Wellesley
39 C. Richard Soderberg..............................Weston
14 Charles Milton Spofford...........................Boston
49 Charles Fayette Taylor............................Cambridge
49 Edward Story Taylor...............................Cambridge
45 Frederick Emmons Terman...........................Palo Alto, Cal.
[28] 44 Karl Terzaghi................................Winchester
49 Hsue-Shen Tsien...................................Pasadena, Cal.
23 Edward Pearson Warner.............................Montreal, Can.
37 Harald Malcolm Westergaard........................Belmont
48 Walter Gordon Whitman.............................Concord
45 John Benson Wilbur................................Belmont
40 John Wulff..Cambridge
41 Vladimir Kosma Zworykin...........................Princeton, N. J.

CLASS II—NATURAL AND PHYSIOLOGICAL SCIENCES—235

SECTION 1—*Geology, Mineralogy, and Physics of the Globe*—43

41 Alan Mara Bateman............................New Haven, Conn.
46 Roland Frank Beers..................................Troy, N. Y.
38 Marland Pratt Billings...............................Wellesley
21 Norman Levi Bowen...........................Washington, D. C.
16 Isaiah Bowman..................................Baltimore, Md.
49 Wilmot Hyde Bradley.........................Washington, D. C.
33 Charles Franklin Brooks..................................Milton
29 Kirk Bryan..Cambridge
49 Walter Herman Bucher..........................New York, N. Y.
48 Arthur Francis Buddington....................Princeton, N. J.
45 Martin Julian Buerger....................................Lincoln
33 Frank Morton Carpenter...............................Lexington
49 Clifford Frondel..Cambridge
42 Russell Gibson...Belmont
49 James Gilluly....................................Los Angeles, Cal.
14 Louis Caryl Graton.....................................Cambridge
17 Herbert Ernest Gregory.........................Honolulu, T. H.
46 Cornelius Searle Hurlbut, Jr............................Belmont
44 Columbus O'Donnell Iselin.........................Woods Hole
02 Thomas Augustus Jaggar.......................Honolulu, T. H.
48 Adolph Knopf...................................New Haven, Conn.
25 Esper Signius Larsen, Jr.........................Arlington, Va.
15 Andrew Cowper Lawson............................Berkeley, Cal.
16 Charles Kenneth Leith..............................Madison, Wis.
31 George Francis McEwen..............................La Jolla, Cal.
49 Hugh Exton McKinstry.................................Cambridge
27 Donald Hamilton McLaughlin...................San Francisco, Cal.
25 Kirtley Fletcher Mather...........................Newton Center
35 Warren Judson Mead.....................................Belmont
17 William John Miller.................................Stockton, Cal.
32 Frederick Kuhne Morris................................Cambridge
34 Walter Harry Newhouse.............................Chicago, Ill.
22 Austin Flint Rogers..................................Palo Alto, Cal.
34 Carl-Gustaf Arvid Rossby............................Chicago, Ill.
19 Waldemar Theodore Schaller...................Washington, D. C.
48 George Gaylord Simpson.........................New York, N. Y.
45 Henry Crosby Stetson....................................Belmont
41 Chester Stock.......................................Pasadena, Cal.
44 Harald Ulrik Sverdrup...............................Oslo, Norway
17 Thomas Wayland Vaughan......................Washington, D. C.
08 Charles Hyde Warren..............................Litchfield, Conn.
35 Derwent Stainthorpe Whittlesey......................Cambridge
15 Frederick Eugene Wright.........................Washington, D. C.

Class II, Section 2—*Botany*—39

30 LeRoy Abrams	Palo Alto, Cal
11 Oakes Ames	North Easton
34 Edgar Anderson	St Louis, Mo
15 Irving Widmer Bailey	Cambridge
00 Liberty Hyde Bailey	Ithaca, N Y
40 Albert Francis Blakeslee	Northampton
49 Lawrence Rogers Blinks	Pacific Grove, Cal
98 Douglas Houghton Campbell	Palo Alto, Cal
48 Edward Sears Castle	Cambridge
49 Jens Christian Clausen	Stanford, Cal
46 Ralph Erskine Cleland	Bloomington, Ind
16 Bradley Moore Davis	Portland, Ore
35 Bernard Ogilvie Dodge	New York, N Y
41 Arthur Johnson Eames	Ithaca, N Y
49 Katherine Esau	Davis, Cal
12 Alexander William Evans	New Haven, Conn
00 Merritt Lyndon Fernald	Cambridge
44 Paul Rupert Gast	Weston
27 Ivan Murray Johnston	Jamaica Plain
34 Donald Forsha Jones	New Haven, Conn
40 Paul Christoph Mangelsdorf	Cambridge
10 Winthrop John Vanleuven Osterhout	New York, N Y
27 George James Peirce	Palo Alto, Cal
49 Kenneth Bryan Raper	Peoria, Ill
44 Hugh Miller Raup	Petersham
48 William Jacob Robbins	New York, N Y
49 Reed Clark Rollins	Cambridge
34 Edmund Ware Sinnott	New Haven, Conn
44 Albert Charles Smith	Washington, D C
34 Gilbert Morgan Smith	Palo Alto, Cal
45 Herman Augustus Spoehr	Palo Alto, Cal
49 Lewis John Stadler	Columbia, Mo
23 Elvin Charles Stakman	St Paul, Minn
48 William Randolph Taylor	Ann Arbor, Mich
38 Kenneth Vivian Thimann	Cambridge
49 Selman Abraham Waksman	New Brunswick, N J
48 Frits Warmolt Went	Pasadena, Cal
22 William Henry Weston, Jr	Winchester
32 Ralph Hartley Wetmore	Cambridge

Class II, Section 3—*Zoology and Physiology*—79

49 Edwin Bennett Astwood	Boston
22 Nathan Banks	Holliston
33 Philip Bard	Baltimore, Md

46 George Wells Beadle.............................Pasadena, Cal.
09 Francis Gano Benedict...........................Machiasport, Me.
11 Henry Bryant Bigelow...........................Concord
14 Robert Payne Bigelow...........................Brookline
35 Charles Henry Blake...........................Lincoln
20 William T. Bovie...........................Fairfield, Me.
24 Edward Allen Boyden...........................Minneapolis, Minn.
16 John Lewis Bremer...........................Boston
28 John Wymond Miller Bunker...........................Belmont
00 William Ernest Castle...........................Berkeley, Cal.
29 Lemuel Roscoe Cleveland...........................Jamaica Plain
26 Edwin Joseph Cohn...........................Cambridge
14 Edwin Grant Conklin...........................Princeton, N. J.
23 Manton Copeland...........................Brunswick, Me.
27 William John Crozier...........................Belmont
29 Hallowell Davis...........................St. Louis, Mo.
33 Alden Benjamin Dawson...........................Belmont
49 Edward Wheeler Dempsey...........................Cambridge
25 Samuel Randall Detwiler...........................New York, N. Y.
43 David Bruce Dill...........................Edgewood Arsenal, Md.
48 Edward Adelbert Doisy...........................St. Louis, Mo.
25 Herbert McLean Evans...........................Berkeley, Cal.
48 Wallace Osgood Fenn...........................Rochester, N. Y.
34 Cyrus Hartwell Fiske...........................Lexington
34 John Farquhar Fulton...........................New Haven, Conn.
48 Herbert Spencer Gasser...........................New York, N. Y.
47 Arnold Lucius Gesell...........................New Haven, Conn.
31 William King Gregory...........................New York, N. Y.
48 Edmund Newton Harvey...........................Princeton, N. J.
36 Frederick Lee Hisaw...........................Belmont
29 Leigh Hoadley...........................Cambridge
34 Hudson Hoagland...........................Shrewsbury
24 Samuel Jackson Holmes...........................Berkeley, Cal.
28 Roy Graham Hoskins...........................Waban
13 Leland Ossian Howard...........................Bronxville, N. Y.
49 George Evelyn Hutchinson...........................New Haven, Conn.
49 Otto Krayer...........................Cambridge
44 Eugene Markley Landis...........................Brookline
16 Frederic Thomas Lewis...........................Waban
14 Ralph Stayner Lillie...........................Chicago, Ill.
49 Cyril Norman Hugh Long...........................New Haven, Conn.
45 John Robert Loofbourow...........................Cambridge
17 Richard Swann Lull...........................New Haven, Conn.
43 Brenton Reid Lutz...........................Melrose
27 Axel Leonard Melander...........................Riverside, Cal.
35 Karl Friedrich Meyer...........................San Francisco, Cal.

21 Gerrit Smith Miller............................Washington, D. C.
42 Hermann Joseph Muller............................Bloomington, Ind.
49 John Spangler Nicholas............................New Haven, Conn.
95 George Howard Parker............................Cambridge
46 James Lee Peters............................Harvard
21 Henry Augustus Pilsbry............................Philadelphia, Pa.
39 Gregory Pincus............................Worcester
27 Frederick Haven Pratt............................Wellesley Hills
09 Herbert Wilbur Rand............................Cambridge
32 David Rapport............................Cambridge
23 Alfred Clarence Redfield............................Woods Hole
34 Alfred Newton Richards............................Bryn Mawr, Pa.
34 Oscar Riddle............................Plant City, Fla.
46 Kenneth David Roeder............................Concord
37 Alfred Sherwood Romer............................Cambridge
25 Alexander Grant Ruthven............................Ann Arbor, Mich.
41 Francis Otto Schmitt............................Belmont
49 Homer William Smith............................New York, N. Y.
49 Tracy Morton Sonneborn............................Bloomington, Ind.
49 Alfred Henry Sturtevant............................Pasadena, Cal.
48 Hubert Bradford Vickery............................New Haven, Conn.
48 George Wald............................Belmont
45 John Henry Welsh, Jr.............................Cambridge
15 Arthur Wisswald Weysse............................Woburn
49 James Walter Wilson............................Providence, R. I.
38 George Bernays Wislocki............................Milton
48 Sewall Wright............................Chicago, Ill.
33 Jeffries Wyman, Jr.............................Chestnut Hill
45 Leland Clifton Wyman............................Jamaica Plain
15 Robert Mearns Yerkes............................New Haven, Conn.

CLASS II, SECTION 4—*Medicine and Surgery*—74

41 Fuller Albright............................Brookline
47 Arthur Wilburn Allen............................Brookline
32 Joseph Charles Aub............................Belmont
36 Oswald Theodore Avery............................Nashville, Tenn.
29 James Bourne Ayer............................Milton
(28) 32 Franklin Greene Balch............................Jamaica Plain
41 Walter Bauer............................Waban
47 David Lawrence Belding............................Hingham
48 Francis Gilman Blake............................New Haven, Conn.
31 George Blumer............................San Marino, Cal.
49 Herrman Ludwig Blumgart............................Boston
43 Arlie Vernon Bock............................Cambridge
36 Charles Sidney Burwell............................Brookline

48 Allan Macy Butler....................................Boston
31 William Bosworth Castle..............................Brookline
30 David Cheever..Boston
13 Henry Asbury Christian...............................Brookline
48 Edward Delos Churchill...............................Belmont
42 William Irving Clark.................................Worcester
49 David Glendenning Cogan..............................Cambridge
21 Rufus Cole...Mount Kisco, N. Y.
31 Eugene Floyd DuBois..................................New York, N. Y.
46 John Franklin Enders.................................Boston
49 Sidney Farber..Cambridge
45 James Morison Faulkner...............................Brookline
44 Maxwell Finland......................................Squantum
33 Reginald Fitz..Brookline
27 James Lawder Gamble..................................Brookline
49 Harry Sylvestre Nutting Greene.......................New Haven, Conn.
49 Robert Edward Gross..................................Boston
22 Joseph Lincoln Goodale...............................Ipswich
45 Thomas Hale Ham......................................Brookline
21 Ross Granville Harrison..............................New Haven, Conn.
49 Arthur Tremain Hertig................................Cambridge
47 Sanford Burton Hooker................................West Roxbury
27 Percy Rogers Howe....................................Belmont
49 Charles Brenton Huggins..............................Chicago, Ill.
33 Edgar Erskine Hume...................................Frankfort, Ky.
34 Henry Jackson, Jr....................................Chestnut Hill
46 Charles Alderson Janeway.............................Weston
12 Elliott Proctor Joslin...............................Boston
43 Chester Scott Keefer.................................Brookline
23 Roger Irving Lee.....................................Brookline
42 Samuel Albert Levine.................................Newton Center
29 Edwin Allen Locke....................................Wilton, N. H.
49 Robert Frederick Loeb................................New York, N. Y.
28 Warfield Theobald Longcope...........................Baltimore, Md.
40 William de Berniere MacNider.........................Chapel Hill, N. C.
44 William Malamud......................................Boston
34 Leroy Matthew Simpson Miner..........................Newtonville
26 George Richards Minot................................Brookline
28 William Lorenzo Moss.................................Athens, Ga.
28 John Howard Mueller..................................West Roxbury
37 Walter Walker Palmer.................................New York, N. Y.
27 Joseph Hershey Pratt.................................Brookline
35 Tracy Jackson Putnam.................................New York, N. Y.
34 William Carter Quinby................................Brookline
47 Francis Minot Rackemann..............................Boston
48 John Rock..Roslindale

34 Arthur Hiler Ruggles............................Providence, R. I.
39 William Thomas Salter..........................New Haven, Conn.
33 George Cheever Shattuck..............................Brookline
47 James Stevens Simmons...................................Boston
47 Richard Mason Smith....................................Boston
30 Torald Hermann Sollmann..........................Cleveland, O.
47 Merrill Clary Sosman..............................Chestnut Hill
46 Siegfried Josef Thannhauser............................Brookline
44 George Widmer Thorn...................................Cambridge
14 Ernest Edward Tyzzer...................................Wakefield
14 Frederick Herman Verhoeff..............................Brookline
47 Shields Warren.....................................West Newton
27 Joseph Treloar Wearn.............................Cleveland, O.
40 Paul Dudley White.....................................Brookline
12 Simeon Burt Wolbach...............................South Sudbury

CLASS III—The Social Arts—189

Section 1—*Jurisprudence*—36

(24) 32 Francis Noyes Balch..........................Jamaica Plain
36 Stoughton Bell...Cambridge
33 Harry Augustus Bigelow.............................Chicago, Ill.
36 Claude Raymond Branch.....................................Boston
48 Charles Allerton Coolidge................................Belmont
49 John Cobb Cooper...............................Princeton, N. J.
33 John Dickinson.................................Philadelphia, Pa.
38 Robert Gray Dodge...Boston
31 Fred Tarbell Field..Newton
40 Lon Louvois Fuller.....................................Cambridge
39 Herbert Funk Goodrich..........................Philadelphia, Pa.
33 Theodore Francis Green..........................Providence, R. I.
38 Frank Washburn Grinnell...................................Boston
41 Erwin Nathaniel Griswold.................................Belmont
39 John Loomer Hall..Boston
39 Augustus Noble Hand.............................New York, N. Y.
33 Learned Hand....................................New York, N. Y.
39 Albert James Harno...............................Urbana, Ill.
49 Charles Antone Horsky..........................Washington, D. C.
47 Mark DeWolfe Howe......................................Cambridge
38 Melvin Maynard Johnson.................................Brookline
49 Phillips Ketchum.......................................Cambridge
38 James McCauley Landis..........................Washington, D. C.
32 Sayre Macneil....................................Pasadena, Cal.
32 Calvert Magruder.......................................Cambridge
31 William DeWitt Mitchell..........................New York, N. Y.

31 Edmund Morris Morgan..............................Cambridge
47 John Lord O'Brian..............................Washington, D. C.
36 Henry Parkman, Jr..............................Boston
01 George Wharton Pepper..............................Philadelphia, Pa.
11 Roscoe Pound..............................Watertown
36 Stanley Elroy Qua..............................Lowell
32 Francis Bowes Sayre..............................Washington, D. C.
21 Austin Wakeman Scott..............................Cambridge
39 Thomas Walter Swan..............................New York, N. Y.
43 Charles Edward Wyzanski, Jr..............................Cambridge

CLASS III, SECTION 2—*Government, International Law, and Diplomacy*—32

36 Howard Landis Bevis..............................Columbus, O.
33 Edwin Montefiore Borchard..............................New Haven, Conn.
46 Harvey Hollister Bundy..............................Boston
40 Robert Granville Caldwell..............................Buenos Aires, Argentina
32 William Richards Castle, Jr..............................Washington, D. C.
32 Joseph Perkins Chamberlain..............................New York, N. Y.
48 William Lockhart Clayton..............................Houston, Tex.
33 Robert Treat Crane..............................Baltimore, Md.
35 Tyler Dennett..............................Hague, N. Y.
46 John Sloan Dickey..............................Hanover, N. H.
27 William Cameron Forbes..............................Norwood
44 Carl Joachim Friedrich..............................Concord
34 Edgar Stephenson Furniss..............................New Haven, Conn.
49 Leland Matthew Goodrich..............................Providence, R. I.
32 Joseph Clark Grew..............................Washington, D. C.
41 Hajo Holborn..............................Hamden, Conn.
27 Arthur Norman Holcombe..............................Cambridge
32 Philip Carryl Jessup..............................New York, N. Y.
49 Walter Lippmann..............................Washington, D. C.
32 Charles Edward Merriam..............................Chicago, Ill.
13 William Bennett Munro..............................Pasadena, Cal.
47 William Phillips..............................North Beverly
41 Gaetano Salvemini..............................Cambridge
46 Robert Burgess Stewart..............................Winchester
44 Sarah Wambaugh..............................Cambridge
47 Sumner Welles..............................Oxon Hill, Md.
43 Payson Sibley Wild, Jr..............................Evanston, Ill.
32 William Franklin Willoughby..............................Washington, D. C.
14 George Grafton Wilson..............................Grafton, Vt.
48 Howard Eugene Wilson..............................New York, N. Y.
27 Quincy Wright..............................Chicago, Ill.
33 Henry Aaron Yeomans..............................Harvard

CLASS III, SECTION 3—*Economics and Sociology*—56

36 James Waterhouse Angell....................New York, N. Y.
47 George Pierce Baker....................Boston
48 Richard Mervin Bissell, Jr....................Washington, D. C.
36 James Cummings Bonbright....................New York, N. Y.
43 Augusta Fox Bronner (Mrs. William Healy)....................Boston
44 Douglass Vincent Brown....................Brookline
46 Theodore Henry Brown....................Cambridge
33 Harold Hitchings Burbank....................Cambridge
34 John Maurice Clark....................Westport, Conn.
28 Arthur Harrison Cole....................Cambridge
21 Clive Day....................New Haven, Conn.
32 Arthur Stone Dewing....................Newton
41 Carl Rupp Doering....................Cambridge
32 Wallace Brett Donham....................Hamilton, N. Y.
36 Fred Rogers Fairchild....................Hamden, Conn.
34 Ralph Evans Freeman....................Cambridge
33 Sheldon Glueck....................Cambridge
34 Robert Murray Haig....................New York, N. Y.
41 Earl Jefferson Hamilton....................Evanston, Ill.
45 Seymour Edwin Harris....................West Acton
49 (Edward) Pendleton Herring....................New York, N. Y.
48 Bishop Carleton Hunt....................Norwell
34 Frank Hyneman Knight....................Chicago, Ill.
36 Roswell Cheney McCrea....................Augusta, Ga.
34 Robert Morison MacIver....................New York, N. Y.
32 Walter Wallace McLaren....................Williamstown
45 William Rupert Maclaurin....................Cambridge
36 Malcolm Perrine McNair....................Cambridge
32 Leon Carroll Marshall....................Chevy Chase, Md.
34 Richard Stockton Meriam....................South Lincoln
32 Frederick Cecil Mills....................New York, N. Y.
34 Arthur Eli Monroe....................Cambridge
34 Edwin Griswold Nourse....................Chevy Chase, Md.
32 William Fielding Ogburn....................Chicago, Ill.
45 Talcott Parsons....................Belmont
42 William Andrew Paton....................Ann Arbor, Mich.
47 Fritz Jules Roethlisberger....................Cambridge
37 Clyde Orval Ruggles....................Cambridge
42 Paul Anthony Samuelson....................Belmont
36 Thomas Henry Sanders....................Cambridge
33 Josef Alois Schumpeter....................Cambridge
43 Benjamin Morris Selekman....................Cambridge
31 Pitirim Alexandrovich Sorokin....................Winchester
41 Francis Trow Spaulding....................Albany, N. Y.

31 Oliver Mitchell Wentworth Sprague......................Cambridge
46 Harold Walter Stoke............................Baton Rouge, La.
49 Philip Taft................................Providence, R. I.
37 Harry Rudolph Tosdal................................Belmont
31 Donald Skeele Tucker................................Belmont
41 Robert Ulich...................................Cambridge
34 Jacob Viner................................Princeton, N. J.
38 T[homas] North Whitehead..........................Cambridge
32 John Henry Williams...............................Cambridge
36 Joseph Henry Willits.........................New York, N. Y.
34 Leo Wolman...................................New York, N. Y.
34 Carle Clark Zimmerman............................Winchester

CLASS III, SECTION 4—*Administration and Affairs*—65

(25) 32 Charles Francis Adams.............................Concord
46 Chester M. Alter...............................West Newton
39 Chester Irving Barnard......................New York, N. Y.
(25) 32 Charles Foster Batchelder.................Peterborough, N. H.
49 Bancroft Beatley.....................................Boston
44 Adolf Augustus Berle, Jr......................New York, N. Y.
49 S(amuel) Bruce Black................................Boston
49 Lloyd DeW. Brace....................................Boston
49 Detlev Wulf Bronk..............................Baltimore, Md.
49 Oliver Ellsworth Buckley......................New York, N. Y.
45 Edwin Sharp Burdell...........................New York, N. Y.
41 Godfrey Lowell Cabot.................................Boston
47 Thomas Dudley Cabot..................................Weston
48 Erwin Dain Canham....................................Newton
47 William Henry Claflin, Jr...........................Belmont
49 Paul Foster Clark....................................Boston
48 Charles Woolsey Cole................................Amherst
43 Ada Louise Comstock (Mrs. Wallace Notestein)......New Haven, Conn.
48 Robert Cutler..Boston
42 Donald Kirk David....................................Boston
48 Herbert John Davis..............................Northampton
38 Edmund Ezra Day................................Ithaca, N. Y.
32 Henry Sturgis Dennison..........................Framingham
46 David Frank Edwards...............................Cambridge
48 Carl Stephens Ell....................................Newton
49 John Wells Farley....................................Boston
(28) 32 William Lusk Webster Field......................Milton
39 Ralph Edward Flanders.........................Springfield, Vt.
38 Horace Sayford Ford................................Belmont
44 Raymond Blaine Fosdick........................New York, N. Y.
48 Francis Calley Gray..................................Boston

49 Harold Daniel Hodgkinson....................Boston
(28) 32 Edward Jackson Holmes....................Topsfield
44 Ernest Martin Hopkins....................Hanover, N. H.
48 Carl Tilden Keller....................Boston
34 Henry Plimpton Kendall....................Sharon
44 James Rhyne Killian, Jr....................Wellesley Hills
39 Morris Evans Leeds....................Philadelphia, Pa.
48 David Eli Lilienthal....................Washington, D. C.
34 Clarence Cook Little....................Bar Harbor, Me.
47 Ralph Lowell....................Westwood
49 Louis Martin Lyons....................Cambridge
36 Dumas Malone....................New York, N. Y.
42 Daniel L. Marsh....................Boston
45 Keyes DeWitt Metcalf....................Belmont
45 Henry Allen Moe....................New York, N. Y.
02 Herbert Putnam....................Washington, D. C.
49 Arthur Grinnell Rotch....................Boston
44 Beardsley Ruml....................New York, N. Y.
34 Erwin Haskell Schell....................Cambridge
38 Charles Seymour....................New Haven, Conn.
35 Henry Lee Shattuck....................Boston
37 Henry Southworth Shaw....................Melrose
48 Alfred Pritchard Sloan, Jr....................New York, N. Y.
49 George A. Sloan....................New York, N. Y.
(28) 32 Payson Smith....................Orono, Me.
46 Huntley Nowell Spaulding....................Rochester, N. H.
33 Albert Warren Stearns....................Billerica
(24) 32 Edwin Sibley Webster....................Brookline
49 Carroll Louis Wilson....................Washington, D. C.
44 Charles Edward Wilson....................New York, N. Y.
41 Laurence Leathe Winship....................South Sudbury
48 Henry Merritt Wriston....................Providence, R. I.
(25) 32 Benjamin Loring Young....................Weston
39 Owen D. Young....................New York, N. Y.

CLASS IV—The Humanities—196

Section 1—*Theology, Philosophy, and Psychology*—44

32 Michael Joseph Ahern....................Weston
33 John Gilbert Beebe-Center....................Swampscott
38 Julius Seelye Bixler....................Waterville, Me.
46 Brand Blanshard....................New Haven, Conn.
24 Edwin Garrigues Boring....................Cambridge
28 Edgar Sheffield Brightman....................Newton
31 Henry Addington Bruce....................Cambridge
49 Millar Burrows....................New Haven, Conn.

32 Leonard Carmichael....Tufts College
48 Rudolph Carnap....Chicago, Ill.
36 Robert Pierce Casey....Providence, R. I.
33 Curt John Ducasse....Providence, R. I.
43 Angus Dun....Washington, D. C.
48 Frederick May Eliot....Cambridge
38 James Everett Frame....Princeton, N. J.
37 Clarence Henry Graham....New York, N. Y.
45 Edwin Ray Guthrie....Seattle, Wash.
32 William Healy....Natick
35 Clark Leonard Hull....New Haven, Conn.
28 Albert Cornelius Knudson....Cambridge
32 Karl Spencer Lashley....Orange Park, Fla.
29 Clarence Irving Lewis....Lexington
42 Richard Peter McKeon....Chicago, Ill.
48 Arthur Edward Murphy....Ithaca, N. Y.
35 Henry Alexander Murray, Jr....Boston
47 Norman Burdett Nash....Boston
32 Arthur Darby Nock....Cambridge
28 Johnson O'Connor....Boston
17 Charles Edwards Park....Boston
33 Carroll Cornelius Pratt....Princeton, N. J.
49 Willard Van Orman Quine....Cambridge
48 Hans Reichenbach....Los Angeles, Cal.
31 Henry Knox Sherrill....New York, N. Y.
27 Willard Learoyd Sperry....Cambridge
29 Russell Henry Stafford....Hartford, Conn.
46 Stanley Smith Stevens....Cambridge
48 Alfred Tarski....Berkeley, Cal.
45 Charles Lincoln Taylor, Jr....Cambridge
34 Lewis Madison Terman....Palo Alto, Cal.
27 Louis Leon Thurstone....Chicago, Ill.
49 Edward Chace Tolman....Berkeley, Cal.
17 John Broadus Watson....Woodbury, Conn.
33 Frederic Lyman Wells....Newton Highlands
35 Robert Sessions Woodworth....New York, N. Y.

CLASS IV, SECTION 2—*History, Archaeology, and Anthropology*—40

41 Warren Ortman Ault....Waban
28 James Phinney Baxter, 3d....Williamstown
27 Robert Pierpont Blake....Cambridge
49 Julian Parks Boyd....Princeton, N. J.
46 Clarence Saunders Brigham....Worcester
42 Henry Joel Cadbury....Cambridge
34 Clarence Gordon Campbell....New York, N. Y.

49 Gilbert Chinard................................Princeton, N. J.
49 Merle (Eugene) Curti................................Madison, Wis.
43 Carleton Stevens Coon................................Devon, Pa.
44 William Bell Dinsmoor................................New York, N. Y.
38 Claude Moore Fuess................................Andover
49 Mason Hammond................................Cambridge
49 James Blaine Hedges................................Providence, R. I.
43 Hugh O'Neill Hencken................................Chestnut Hill
14 Bert Hodge Hill................................Athens, Greece
27 Earnest Albert Hooton................................Cambridge
33 Halford Lancaster Hoskins................................Washington, D. C.
47 Wilbur Kitchener Jordan................................Cambridge
44 Clyde Kay Maben Kluckhohn................................Cambridge
12 Alfred Louis Kroeber................................Berkeley, Cal.
44 Ambrose Lansing................................New York, N. Y.
49 Kenneth Scott Latourette................................New Haven, Conn.
32 Waldo Gifford Leland................................Newton
41 William E. Lingelbach................................Philadelphia, Pa.
48 Margaret Mead................................New York, N. Y.
38 Stewart Mitchell................................Cambridge
15 Samuel Eliot Morison................................Boston
46 Otto Eduard Neugebauer................................Princeton, N. J.
34 Robert Henry Pfeiffer................................Cambridge
34 David Moore Robinson................................University, Miss.
23 Michael Ivanovich Rostovtzeff................................New Haven, Conn.
27 George Sarton................................Cambridge
38 Bernadotte Everly Schmitt................................Alexandria, Va.
36 Donald Scott................................Cambridge
49 Richard Harrison Shryock................................Baltimore, Md.
26 Herbert Joseph Spinden................................Brooklyn, N. Y.
32 Charles Holt Taylor................................Cambridge
11 Alfred Marston Tozzer................................Cambridge
39 Henry Rouse Viets................................Brookline

Class IV, Section 3—*Philology*—50

35 Charles Henry Beeson................................Chicago, Ill.
48 Bernard Bloch................................New Haven, Conn.
33 Campbell Bonner................................Ann Arbor, Mich.
41 Giuseppe Antonio Borgese................................Chicago, Ill.
21 Carl Darling Buck................................Chicago, Ill.
49 Oscar James Campbell................................New York, N. Y.
18 Edward Capps................................Princeton, N. J.
48 Yuen Ren Chao................................Berkeley, Cal.
20 Walter Eugene Clark................................Cambridge
46 George Raleigh Coffman................................Chapel Hill, N. C.

32 Ronald Salmon Crane....Chicago, Ill.
32 Morris William Croll....Princeton, N. J.
44 Henry Grattan Doyle....Washington, D. C.
20 Franklin Edgerton....New Haven, Conn.
40 Serge Elisséeff....Cambridge
14 Jeremiah Denis Mathias Ford....Cambridge
16 Louis Herbert Gray....New York, N. Y.
25 William Chase Greene....Cambridge
13 Charles Burton Gulick....Scarsdale, N. Y.
34 Austin Morris Harmon....Chebeague Island, Me.
31 Raymond Dexter Havens....Baltimore, Md.
18 George Lincoln Hendrickson....New Haven, Conn.
17 William Guild Howard....Cambridge
40 Werner Wilhelm Jaeger....Watertown
32 (Ralph) Hayward Keniston....Ann Arbor, Mich.
34 Roland Grubb Kent....Wynnewood, Pa.
33 Hans Kurath....Ann Arbor, Mich.
39 Henry Carrington Lancaster....Baltimore, Md.
33 Ivan Mortimer Linforth....Berkeley, Cal.
44 Elias Avery Lowe....Princeton, N. J.
35 Benjamin Dean Meritt....Princeton, N. J.
28 William Albert Nitze....Los Angeles, Cal.
32 George Rapall Noyes....Berkeley, Cal.
33 Howard Rollin Patch....Northampton
32 Arthur Stanley Pease....Cambridge
11 Fred Norris Robinson....Cambridge
38 Hyder Edward Rollins....Cambridge
31 Robert Kilburn Root....Princeton, N. J.
35 Henry Arthur Sanders....Ann Arbor, Mich.
43 Jean Joseph Seznec....Cambridge
45 George Wiley Sherburn....Cambridge
45 Taylor Starck....Cambridge
49 Archer Taylor....Berkeley, Cal.
32 William Thomson....South Lincoln
11 Charles Cutler Torrey....New Haven, Conn.
47 William Freeman Twaddell....Providence, R. I.
48 Berthold Louis Ullman....Chapel Hill, N. C.
30 Ernest Hatch Wilkins....Newton Center
33 Harry Austryn Wolfson....Cambridge
49 Louis Booker Wright....Washington, D. C.

CLASS IV, SECTION 4—*The Fine Arts and Belles Lettres*—62

43 Leonard Bacon....Peace Dale, R. I.
26 Frank Weston Benson....Salem
32 (William) Welles Bosworth....Locust Valley, N. Y.
49 Van Wyck Brooks....Bridgewater, Conn.

47 Richard Burgin....................................Brookline
42 John Nash Douglas Bush................................Cambridge
33 John Alden Carpenter................................Carmel, Cal.
45 Samuel Chamberlain ....Marblehead
32 Chalmers Dancy Clifton............................New York, N. Y.
49 Robert Peter Tristram Coffin........................Brunswick, Me.
32 Kenneth John Conant................................Cambridge
46 William George Constable..........................Cambridge
49 Bernard Augustine DeVoto..........................Cambridge
47 John Roderigo Dos Passos.........................Provincetown
49 William Addison Dwiggins...........................Hingham
32 George Harold Edgell...............................Cambridge
21 William Emerson...................................Cambridge
30 John Erskine.....................................New York, N. Y.
18 Edward Waldo Forbes...............................Cambridge
49 Esther Forbes......................................Worcester
31 Robert Frost.................................South Shaftsbury, Vt.
27 Wallace Goodrich..................................Manchester
44 Walter Gropius......................................Lincoln
48 Bartlett Harding Hayes, Jr...............................Andover
31 Robert Silliman Hillyer...........................Greenwich, Conn.
27 Charles Hopkinson.................................Manchester
12 Mark Antony DeWolfe Howe..............................Boston
38 Joseph Hudnut.....................................Cambridge
18 Archer Milton Huntington.......................New York, N. Y.
45 William Alexander Jackson..........................Cambridge
38 Howard Mumford Jones...............................Cambridge
42 Otto Kinkeldey.................................New York, N. Y.
49 Jack Levine.....................................New York, N. Y.
47 Milton Edward Lord...................................Boxford
21 Charles Donagh Maginnis............................Brookline
49 Thomas Mann...............................Pacific Palisades, Cal.
31 Paul Manship....................................New York, N. Y.
48 John Marin......................................Cliffside Park, N. J.
31 Daniel Gregory Mason...........................New York, N. Y.
31 Frank Jewett Mather............................Princeton, N. J.
44 Charles Rufus Morey................................Rome, Italy
47 Lewis Mumford...................................New York, N. Y.
48 Thomas Munro.....................................Cleveland, O.
31 Kenneth Ballard Murdock...............................Boston
48 Erwin Panofsky..................................Princeton, N. J.
(24) 32 Anthony John Philpott..........................Arlington
41 Walter Hamor Piston, Jr..............................Belmont
21 Chandler Rathfon Post.............................Cambridge
49 Lucien Price..Boston
22 Paul Joseph Sachs..................................Cambridge

14 Ellery Sedgwick................................Beverly
19 Henry Dwight Sedgwick................................Dedham
48 Bruce Simonds................................Hamden, Conn.
48 John Sloan................................New York, N. Y.
39 Francis Henry Taylor................................New York, N. Y.
43 Randall Thompson................................Cambridge
44 Karl Viëtor................................Cambridge
45 Martin Wagner................................Cambridge
46 Edward Augustus Weeks, Jr................................Boston
39 Karl Ephraim Weston................................Williamstown
44 Herbert Eustis Winlock................................North Haven, Me.
46 William Wilson Wurster................................Cambridge

FELLOWS EMERITI—48

CLASS I—Mathematical and Physical Sciences—9

Class I, Section 1—2

15 Frank Lauren Hitchcock................................Belmont
[12] 44 Frederick Shenstone Woods................................Newton Center

Class I, Section 2—1

12 Maurice deKay Thompson................................Boston

Class I, Section 3—3

14 Samuel Cate Prescott................................Brookline
40 William Lloyd Evans................................Columbus, O.
15 George Shannon Forbes................................Cambridge

Class I, Section 4—3

23 William Hovgaard................................Morristown, N. J.
32 Ralph Restieaux Lawrence................................Belmont
30 George Edmond Russell................................Lexington

CLASS II—Natural and Physiological Sciences—14

Class II, Section 1—5

09 Reginald Aldworth Daly................................Cambridge
34 Sterling Price Fergusson................................Milton
[03] 44 Charles Palache................................Cambridge
17 Percy Edward Raymond................................Lexington
11 Hervey Woodburn Shimer................................Hingham

Class II, Section 2—2

29 Joseph Horace Faull................................Cambridge
21 Elmer Drew Merrill................................Jamaica Plain

Class II, Section 3—3

15 Charles Thomas Brues................................Newtonville
22 Thorne Martin Carpenter................................Foxboro
15 Alexander Forbes................................Milton

Class II, Section 4—4

32 Fred Bates Lund....................................Newton Center
25 Robert Bayley Osgood....................................Boston
32 Frederick Fuller Russell............................Louisville, Ky.
30 Fritz Bradley Talbot....................................Brookline

CLASS III—The Social Arts—7

Class III, Section 1—1

(28) 32 Edmund Allen Whitman..............................Cambridge

Class III, Section 2—1

31 Sidney Bradshaw Fay....................................Cambridge

Class III, Section 3—3

32 William James Cunningham..............................Cambridge
32 Henry Wyman Holmes....................................Cambridge
33 Abbott Payson Usher..............................Madison, Wis.

Class III, Section 4—2

35 Jerome Davis Greene....................................Cambridge
36 Clair Elsmere Turner....................................Arlington

CLASS IV—The Humanities—18

Class IV, Section 1—4

28 Walter Fenno Dearborn....................................Cambridge
30 William Henry Paine Hatch..............................Arlington
21 William Ernest Hocking..........................Madison, N. H.
28 Henry Bradford Washburn..............................Cambridge

Class IV, Section 2—4

12 George Henry Chase....................................Cambridge
21 William Scott Ferguson....................................Cambridge
22 George La Piana....................................Wellesley
20 Charles Howard McIlwain..........................Princeton, N. J.

Class IV, Section 3—5

38 Richmond Laurin Hawkins..............................Cambridge
32 Ernest Felix Langley....................................Cambridge
44 La Rue Van Hook..............................New York, N. Y.
33 George Benson Weston....................................Cambridge
39 William Hoyt Worrell..........................Ann Arbor, Mich.

Class IV, Section 4—5

29 Charles Townsend Copeland..............................Cambridge
41 Archibald Thompson Davison..............................Lincoln
29 Edward Burlingame Hill........................Francestown, N. H.
[35] 44 Walter Raymond Spalding..........................Cambridge
22 Charles Henry Conrad Wright..........................Cambridge

FOREIGN HONORARY MEMBERS—127

(Number limited to one hundred and fifty)

CLASS I—MATHEMATICAL AND PHYSICAL SCIENCES—35

SECTION 1—*Mathematics and Astronomy*—12

39 Arnaud Denjoy........Paris
34 Ronald Aylmer Fisher........Cambridge, England
20 Jacques Salomon Hadamard........Paris
27 Ejnar Hertzsprung........Leiden
45 Sir Harold Spencer Jones........Greenwich
46 Bertil Lindblad........Stockholm
47 Edward Arthur Milne........Oxford
46 Jan Hendrik Oort........Leiden
47 Meghnad N. Saha........Calcutta
47 G. A. Shajn........Simeis, U. S. S. R.
15 Charles Jean de la Vallée Poussin........Louvain
29 Hermann Weyl........Princeton, N. J.

CLASS I, SECTION 2—*Physics*—8

29 Vilhelm Frimann Koren Bjerknes........Oslo
45 Niels Bohr........Copenhagen
24 Albert Einstein........Princeton, N. J.
29 James Franck........Chicago, Ill.
29 Abram F. Joffé........Leningrad
48 Max Felix Theodor von Laue........Göttingen
48 Arnold Sommerfeld........Munich
47 Sir George Paget Thomson........London

CLASS I, SECTION 3—*Chemistry*—9

27 Peter Debye........Ithaca, N. Y.
33 Jaroslav Heyrovsky........Prague
33 Fritz Paneth........Durham
48 Sir Robert Robinson........Oxford
38 Leopold Ruzicka........Zürich
38 Nevil Vincent Sidgwick........Oxford
48 The Svedberg........Upsala
49 Chaim Weizmann........Rehovoth, Israel
29 Heinrich Wieland........Munich

CLASS I, SECTION 4—*Technology and Engineering*—6

36 Edward Victor Appleton....................................London
46 Clarence Decatur Howe....................................Ottawa
34 Luigi Lombardi....................................Rome
29 Ludwig Prandtl....................................Göttingen
29 Emil Probst....................................Oxford
31 Karl Willy Wagner....................................Friedrichsdorf

CLASS II—NATURAL AND PHYSIOLOGICAL SCIENCES—28

SECTION 1—*Geology, Mineralogy, and Physics of the Globe*—6

36 Raoul Blanchard....................................Grenoble, France
29 Léon William Collet....................................Geneva
34 Arthur Holmes....................................Edinburgh
22 Emmanuel de Margerie....................................Paris
44 Ezequiel Ordoñez....................................Mexico, D. F.
47 Wong Wen-hao....................................Nanking

CLASS II, SECTION 2—*Botany*—8

48 P. Boysen-Jensen....................................Copenhagen
46 Rudolf Florin....................................Stockholm
47 P. Maheshwari....................................Dacca, India
32 Kingo Miyabe....................................Sapporo, Japan
42 Lorenzo Raimundo Parodi....................................Buenos Aires
47 Alf Erling Porsild....................................Ottawa
29 Otto Renner....................................Jena
35 Sir William Wright Smith....................................Edinburgh

CLASS II, SECTION 3—*Zoology and Physiology*—8

38 Edgar Douglas Adrian....................................Cambridge, England
48 Charles Herbert Best....................................Toronto
20 Maurice Caullery....................................Paris
38 Emmanuel Fauré-Frémiet....................................Paris
34 Archibald Vivian Hill....................................London
41 Bernado Alberto Houssay....................................Buenos Aires
48 Archibald Gowanlock Huntsman....................................Toronto
30 Louis Édouard Lapicque....................................Paris

CLASS II, SECTION 4—*Medicine and Surgery*—6

39 Sir Aldo Castellani....................................Rome
27 Sir Henry Hallett Dale....................................London
33 Sir Arthur Keith....................................London
28 Mikinosuke Miyajima....................................Tokyo
18 Sir Charles Scott Sherrington....................................Cambridge, England
36 (Jean) Hyacinthe Vincent....................................Paris

CLASS III—THE SOCIAL ARTS—32

SECTION 1—*Jurisprudence*—12

44 Victor Andres Belaunde....................................Lima
47 Paal Berg....................................Oslo
38 François Geny....................................Nancy
38 Arthur Lehman Goodhart....................................Oxford
39 Baron Greene (Wilfrid Arthur Greene).....Holmbury St. Mary, Surrey
33 Hans Kelsen....................................Berkeley, Cal.
38 Baron Macmillan (Hugh Pattison Macmillan)........Ewhurst, Surrey
33 Juljusz Makarewicz....................................Lwów
48 Léon Julliot de la Morandière....................................Paris
33 Giorgio Del Vecchio....................................Rome
38 Baron Wright (Robert Alderson Wright)..............Burbage, Wilts
38 John C. H. Wu....................................Vatican City

SECTION 2—*Government, International Law, and Diplomacy*—7

48 José d'Almada....................................Lisbon
38 Dionisio Anzilotti....................................Rome
46 Winston Churchill....................................London
32 Paul Claudel....................................Paris
32 Hu Shih....................................Peiping
38 Kenzo Takayanagi....................................Tokyo
49 Sir Alfred Zimmern....................................Hartford, Conn.

SECTION 3—*Economics and Sociology*—9

32 Arthur Lyon Bowley....................................Haslemere, Surrey
39 Henry Clay....................................Oxford
44 Daniel Cosío Villegas....................................Mexico, D. F.
35 Luigi Einaudi....................................Rome
32 Ralph George Hawtrey....................................London
35 René Maunier....................................Paris
28 Arthur Cecil Pigou....................................Cambridge, England
32 Charles Rist....................................Versailles
45 Dennis Holme Robertson....................................Cambridge, England

SECTION 4—*Administration and Affairs*—4

38 Gösta A. Bagge....................................Stockholm
38 Heinrich Brüning....................................Cambridge, Mass.
45 Alfredo Lorenzo Palacios....................................Buenos Aires
38 B. Seebohm Rowntree....................................North Dean, Bucks

CLASS IV—THE HUMANITIES—32

SECTION 1—*Theology, Philosophy, and Psychology*—6

28 Benedetto Croce . . . . . Naples
29 Étienne Gilson . . . . . Melun
28 Wolfgang Köhler . . . . . Swarthmore, Pa.
37 Henri Piéron . . . . . Paris
46 Francisco Romero . . . . . Buenos Aires
47 Godfrey Hilton Thomson . . . . . Edinburgh

SECTION 2—*History, Archaeology, and Anthropology*—6

33 Rafael Altamira y Crevea . . . . . Madrid
36 Marcel Aubert . . . . . Paris
33 Friedrich Meinecke . . . . . Berlin-Dahlem
40 Martin Persson Nilsson . . . . . Lund
49 Arnold Joseph Toynbee . . . . . Oxford
31 George Macaulay Trevelyan . . . . . Cambridge, England

SECTION 3—*Philology*—9

44 Amado Alonso . . . . . Arlington, Mass.
47 Hamilton Alexander Rosskeen Gibb . . . . . Oxford
47 Joseph Klausner . . . . . Jerusalem
36 Paul Kretschmer . . . . . Vienna
32 Paul Mazon . . . . . Paris
17 Ramón Menéndez Pidal . . . . . Madrid
45 Tomás Navarro Tomás . . . . . New York, N. Y.
[12] 28 Hanns Oertel . . . . . Munich
32 Frederick William Thomas . . . . . Bodicote nr. Banbury

SECTION 4—*The Fine Arts and Belles Lettres*—11

40 Fernand Baldensperger . . . . . Paris
48 Jean-Marie Carré . . . . . Paris
40 Paul Hindemith . . . . . New Haven, Conn.
34 Serge Koussevitzky . . . . . Brookline
27 Gilbert Murray . . . . . Oxford
49 Oscar Niemeyer . . . . . Rio de Janeiro
31 Edgar Allison Peers . . . . . Liverpool
48 Jan Hendrik Scholte . . . . . Amsterdam
49 Levin Ludwig Schücking . . . . . Erlangen, Bavaria
41 Jean Julius Christian Sibelius . . . . . Helsinki
40 Igor Stravinsky . . . . . Hollywood, Cal.

ALPHABETICAL INDEX TO LISTS OF MEMBERS

The letters F, FE and FHM refer to the lists of Fellows, Fellows Emeriti and Foreign Honorary Members, respectively. The class and section are indicated by the numerals following.

STATUTES

The American Academy of Arts and Sciences

Adopted November 8, 1911: *amended* May 8, 1912, *January* 8, *and May* 14, 1913, *April* 14, 1915, *April* 12, 1916, *April* 10, 1918, *May* 14, 1919, *February* 8, *April* 12, *and December* 13, 1922, *February* 14, *March* 14, *and October* 10, 1923, *March* 10, 1926, *May* 9, 1928, *April* 8, *and November* 11, 1931, *April* 12, 1933, *February* 14, 1934, *December* 14, 1938, *January* 11, *April* 12, 1939, *May* 8, 1940, *May* 14, 1941, *November* 18, 1942, *and January* 12, 1944, *May* 9, 1945, *November* 14, 1945, *February* 2, 1946, *October* 9, 1946, *and October* 8, 1947.

CHAPTER I

The Academy and Its Corporate Seal

Article 1. The American Academy of Arts and Sciences is a body politic and corporate by the same name, forever, established by the Council and House of Representatives in General Court of the Province of Massachusetts Bay as recorded in Chap. 46 of the Acts of 1779.

Article 2. As enacted above, the stated end and design of the institution of the said Academy is to promote and encourage the knowledge of the antiquities of America, and of the natural history of the country, and to determine the uses to which the various natural productions of the country may be applied; to promote and encourage medical discoveries, mathematical disquisitions, philosophical enquiries and experiments, astronomical, meteorological and geographical observations; and improvements in agriculture, arts, manufacture and commerce; and, in fine, to cultivate every art and science which may tend to advance the interest, honor, dignity and happiness of a free, independent and virtuous people.

Article 3. The Corporate Seal of the Academy shall be as here depicted.

ARTICLE 4. The Secretary shall have the custody of the Corporate Seal.

See Chap. v, art. 3; chap. vi, art. 1.

CHAPTER II

MEMBERSHIP AND DUES

ARTICLE 1. The Academy shall consist of Fellows, elected from the citizens or residents of the United States of America, Fellows Emeriti, and Foreign Honorary Members. They are arranged in four Classes, according to the Arts and Sciences in which they are severally proficient, and each Class shall be divided into four Sections, namely:

CLASS I. *The Mathematical and Physical Sciences*
- Section 1. Mathematics and Astronomy
- Section 2. Physics
- Section 3. Chemistry
- Section 4. Technology and Engineering

CLASS II. *The Natural and Physiological Sciences*
- Section 1. Geology, Mineralogy, and Physics of the Globe
- Section 2. Botany
- Section 3. Zoology and Physiology
- Section 4. Medicine and Surgery

CLASS III. *The Social Arts*
- Section 1. Jurisprudence
- Section 2. Government, International Law, and Diplomacy
- Section 3. Economics and Sociology
- Section 4. Administration and Affairs

CLASS IV. *The Humanities*
- Section 1. Theology, Philosophy, and Psychology
- Section 2. History, Archaeology, and Anthropology
- Section 3. Philology
- Section 4. The Fine Arts and Belles Lettres

ARTICLE 2. The number of Fellows shall not exceed one thousand, of whom not more than eight hundred shall be residents of Massachusetts, nor shall there be more than two hundred and seventy-five in any one Class.

Any Fellow of the Academy on retiring from his academic or other regular duties may, if he so requests in writing, and with the approval of the Council, be transferred to the status of Fellow Emeritus.

Fellows Emeriti shall be exempt from payment of dues. They may not hold elective office in the Academy, nor serve on Standing Com-

mittees, nor vote at meetings, but shall have all the other privileges of Fellowship.

Fellows Emeriti shall be separately classified and shall be outside the statutory limit set on the total number of Fellows and the number in a given Class.

See Chap. ix, art. 3; chap. x, art. 1.

ARTICLE 3. The number of Foreign Honorary Members shall not exceed one hundred and fifty. They shall be chosen from citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated. There shall be not more than forty-five in any one Class.

ARTICLE 4. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretary, shall be given to Fellows and Foreign Honorary Members.

ARTICLE 5. If any person, after being notified of his election as Fellow or Foreign Honorary Member, shall neglect for six months to accept in writing, his election shall be void.

ARTICLE 6. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of ten dollars: if he shall neglect to pay this Fee within six months of the date of his election, his election shall become void.

Every Fellow resident within fifty miles of Boston shall pay such Annual Dues, not exceeding fifteen dollars, as shall be voted by the Academy at each Annual Meeting, at which time they shall become due.

Every Fellow residing more than fifty miles from Boston elected after 1938 shall pay, and other non-resident Fellows may pay, Annual Dues equal to one-half the amount set for resident Fellows at each Annual Meeting and due on the same date.

Any Fellow shall be exempt from further payment of Annual Dues who has paid such dues for forty years, or having attained the age of seventy-five, has paid dues for twenty-five years.

Any Fellow may also be exempt from further payment of annual dues upon payment into the treasury of the Academy the sum of two hundred dollars in addition to his previous payments.

Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer, within three months thereafter, Annual Dues for the current year, and if he shall neglect to make this payment within the specified time,

after having been notified by the Treasurer of the requirements of this Article of the Statutes, he shall cease to be a Fellow.

ARTICLE 7. Any Fellow, resident or non-resident, who shall neglect to pay his Annual Dues for six months after they are due and who ignores notification by the Treasurer of the requirements of this Article of the Statutes shall cease to be a Fellow.

ARTICLE 8. Only Fellows who pay Annual Dues or have commuted them may hold elective office in the Academy or serve on Standing Committees or vote at meetings.

ARTICLE 9. Upon petition of any Fellow, the Council may by a majority vote suspend the application of any penalties hereinabove prescribed in this chapter for an additional period of time not longer than three months.

ARTICLE 10. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three-fourths of the Fellows present out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii; chap. vi, art. 5 and 6; chap. x, art. 1.

CHAPTER III

NOMINATION AND ELECTION OF FELLOWS AND FOREIGN HONORARY MEMBERS

The procedure for nomination and election of Fellows and Foreign Honorary Members shall be as follows:

ARTICLE 1. Nominations may be made at any time by any two Fellows in writing on forms to be provided by the Secretary and shall be referred by him to the Committee on Membership.

The Committee on Membership shall meet following the stated meetings of the Academy in May, November, February and March, and at such other times as it may determine, to appraise nominations received by it from the Fellows from time to time, to originate further nominations, and to approve as candidates for election those receiving the favorable vote of two-thirds of the committee members present in any meeting attended by not less than five of its members.

Immediately following its meeting in February, the Committee shall cause to be sent to every Fellow a list of nominees, with biographical

and professional data thereon, together with names of nominators, for appraisal, expression of preference, or other comment by the Fellows.

The Committee, at its March meeting, shall review all nominations, together with comments by the Fellows thereon, and shall compile a list of approved candidates for the annual election of Fellows and Foreign Honorary Members. It shall present this list together with data pertaining thereto to the Council not later than at the Stated Meeting of the Council in April.

The Council, by vote of the majority of members present at a meeting, shall make final nominations from the list of approved persons recommended by the Committee on Membership for election by the Fellows.

ARTICLE 2. Election of Fellows and Foreign Honorary Members shall be made by a majority of the Fellows present at the Annual Meeting in May, from the nominations presented at that meeting by the Council.

ARTICLE 3. Each Fellow or Foreign Honorary Member shall be notified in writing by the Secretary immediately following his election.

See Chap. ii; chap. vi, art. 5; chap. x, art. 1; chap. xi, art. 1 (ii).

CHAPTER IV
OFFICERS

ARTICLE 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), four Vice-Presidents (one from each Class), a Secretary (who shall be Secretary of the Council), a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall take office at the close of that meeting, and shall hold their respective offices for one year, and until others are duly chosen and take office.

There shall be also sixteen Councillors, one from each Section of each Class. At each Annual Meeting four Councillors, one from each Class, shall be elected by ballot to serve for a term of four years, and they shall take office at the close of that meeting, and shall hold office until others are duly chosen and take office. The same Fellows shall not be eligible for two successive terms.

The Councillors, with the officers previously named, and the Chairmen of the Standing Committees, *ex officiis*, shall constitute the Council.

See Chap. xi, art. 1.

ARTICLE 2. If any officer be unable, through death, absence, or disability, to fulfill the duties of his office, or if he shall resign, his

place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

ARTICLE 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of four Fellows having the right to vote, one from each Class This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Secretary not later than four weeks before the Annual Meeting.

ARTICLE 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Secretary not less than ten days before the Annual Meeting, shall be included in the election procedure.

ARTICLE 5. The Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V

THE PRESIDENT

ARTICLE 1. The President, or in his absence a Vice-President, shall preside at meetings of the Academy.

See Chap. vi, art. 3.

ARTICLE 2. The President shall be the chief executive officer of the Academy. He shall present to the Council for its consideration all matters pertinent to the interests of the Academy and to the discharge of its obligations to the community or to the advancement of scholarship.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized by the Council.

ARTICLE 4. In case of incapacity of the President, the Council shall designate a Vice-President to carry out the duties of the office.

See Chap. ii, art. 4; chap. iv, art. 1, 3; chap. vi, art. 3; chap. viii, art. 4; chap. x, art. 3; chap. xi, art. 1 (ii), (iii), (x); chap. xii, art. 1.

CHAPTER VI

THE SECRETARY

ARTICLE 1. The Secretary shall provide for the custody of the Charter, Corporate Seal, Statute Book, Journals of the Academy, and other Archives.

Article 2. He shall be responsible for the correspondence of the Academy and of the Council. At each meeting of the Council he shall present any important communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such matters as the Council may determine.

Article 3. He shall attend the meetings of the Academy and the Council and shall arrange for the keeping of a faithful record of the attendance and of the proceedings. In the absence of the President and of all the Vice-Presidents, he shall call the meeting to order and preside until a chairman is chosen by majority vote of the Fellows present.

Article 4. He shall apprise officers and committees of their election or appointment, and inform the Treasurer and the Chairman of each Standing Committee of appropriations of money voted by the Academy.

Article 5. He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma. After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

Article 6. He shall keep and cause to be printed annually a list of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections, and a list of Fellows and Foreign Honorary Members of whose deaths he has been informed.

Article 7. He shall arrange for the preservation of records of the death of Fellows and Foreign Honorary Members and biographical notices published on the occasion of their death, or at other times.

See Chap. i, art. 2; chap. ii, art. 4; chap. iii; chap. iv, art. 1, 3, 4, 5; chap. ix, art. 3; chap. xi, art. 1 (iii), 2; chap. xii, art. 1, 3.

CHAPTER VII

The Treasurer and the Treasury

Article 1. The Treasurer shall collect all money due or payable to the Academy and all gifts or bequests made to it. He shall pay all bills due and payable by the Academy when approved by the proper officers. He shall sign all leases of real estate in the name of the Academy. He shall be the official custodian of all bonds, stocks and other securities and, with the written approval of any one member of

the Committee on Finance, he shall have full authority to sell and transfer, invest and reinvest from time to time in such manner and upon such terms as shall to him seem best, the whole or any part of the personal property of the said Academy.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the appropriation thereof, and render them annually.

He shall fund all payments received in commutation of Dues, their income only to be applied toward current expenditures.

His accounts shall always be open to the inspection of the Council.

Article 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources, together with appropriations needed by Officers and Standing Committees for the ensuing fiscal year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues.

Article 3. He shall give such security for the trust reposed in him as the Academy may require.

Article 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

Article 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

Article 6. The Financial Year of the Academy shall begin with the first day of April.

Article 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy,

except cash or invested funds, without previous consent and approval of the Council.

See Chap. ii, art. 2, 6, 7, 8; chap. iv, art. 1; chap. vi, art. 4; chap. ix, art. 6; chap. xi, art. 1 (i), (iv), (v), art. 2; chap. xii, art. 1.

CHAPTER VIII

The Librarian and the Library

Article 1. The Librarian shall have charge of the Library and keep a correct catalog of it.

Article 2. The Librarian shall have authority to expend such sums as may be appropriated by the Academy for the purchase, repair, or maintenance of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

Article 3. All books procured from the income of the Rumford Fund or other special funds shall contain a bookplate expressing the fact.

Article 4. The Librarian shall have the custody of the publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. iv, art. 1; chap. xi.

CHAPTER IX

The Editor and the Publications

Article 1. The Editor shall have charge of the conduct through the press of the publications of the Academy. Together with the Committee on Publication he shall determine the contents of the publications.

Article 2. The publications of the Academy shall be as follows:

(i) The Proceedings shall be published at least semi-annually as soon as may be possible after the Annual May Meeting, and the stated December meeting next following, and shall contain a record of each stated or special meeting of the Academy. They shall be known respectively as the Summer and Winter numbers of the Proceedings.

The Summer number of the Proceedings shall include reports of the officers and standing committees for the preceding year; a list of the officers, councillors and members of standing committees elected at the preceding Annual Meeting; and such other matter as the Publication Committee may approve.

The Winter number of the Proceedings shall include a current list of officers, councillors, standing committees, Fellows and Foreign Honorary Members; the Statutes of the Academy; the Act of Incorporation of 1780 and its amendments; and such biographical notices or other matter as the Committee on Publication may approve.

In the discretion of the Committee on Publication, interim numbers of the Proceedings may be issued for the publication of accepted serial papers or other scholarly material.

(ii) Memoirs, monographs and volumes of collected papers may be published from time to time.

(iii) The Bulletin of the American Academy of Arts and Sciences shall be published eight times each year preceding the stated meetings, containing notices of such meetings, communications from the Council or Officers, and such other matter as may be of timely interest to the Fellows.

ARTICLE 3. A copy of the Summer and Winter numbers of the Proceedings shall be mailed to each Fellow, Fellow Emeritus, and Foreign Honorary Member.

A copy of the Bulletin shall be mailed to each Fellow and Fellow Emeritus.

A copy of any Interim number of the Proceedings shall be mailed only to those Fellows, Fellows Emeriti, and Foreign Honorary Members, who shall make written request to the Secretary for that number.

ARTICLE 4. Fellows who pay or have commuted the Annual Dues, Fellows Emeriti, and Foreign Honorary Members shall be entitled, upon written request to the Librarian, to receive gratis one copy of each number of Proceedings, Memoirs, monographs or series of collected papers, published by the Academy, which have been issued after their election, and are available.

ARTICLE 5. Not more than two hundred extra copies of each paper printed in the Proceedings shall be placed at the disposal of the author without charge.

ARTICLE 6. The Editor shall have the authority to expend for printing and other expenses of publication such sums as may be appropriated by the Academy for such purposes; also such sums as may be made available to him by the Council from any source for particular publications under the sponsorship of the Academy.

See Chap. iv, art. 1; chap. xi, art. 1 (vi).

CHAPTER X

The Council

Article 1. The Council shall exercise general supervision over all affairs of the Academy not explicitly reserved to the Academy as a whole.

It shall consider all nominations of Fellows and Foreign Honorary Members duly sent to it by the Committee on Membership, and act upon them in accordance with the provisions of Chapter III.

With the consent of the person concerned it shall have power to present to the Academy a proposal to transfer in respect to status, Class, or Section.

Article 2. Nine members shall constitute a quorum.

Article 3. It shall act upon all resignations and forfeitures of membership in the Academy.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation. They shall hold their respective positions during the pleasure of the Council.

It shall fill any vacancy caused by death, resignation or incapacity of any officer.

Article 4. It may appoint for terms not exceeding one year, and prescribe the functions of such committees of its number or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

Article 5. At the stated March meeting of the Academy it shall recommend for action the appropriations which in the opinion of the Council should be made for the ensuing fiscal year and the Annual Dues therefor.

It may recommend special appropriations at any Stated Meeting of the Academy, or at a Special Meeting, in the call for which such business shall have been included.

See Chap. ii, art. 2, 10; chap. iii, art. 1, 2; chap. iv, art. 1, 2; chap. v, art. 2, 3; chap. vi, art. 2, 3; chap. vii, art. 1, 2, 7; chap. ix, art. 6; chap. xi, art. 1; chap. xii, art. 1, 4, 6.

CHAPTER XI

Standing Committees

Article 1. At the Annual Meeting of the Corporation the following Standing Committees shall be elected by ballot of the Fellows to serve from the time of their election until their successors shall have been elected.

(i) *The House Committee* shall consist of three Fellows who shall have general charge of maintaining the House of the Academy in suitable condition for the uses thereof approved by the Council.

The Chairman of the House Committee or his designate shall approve in writing all expenditures for repairs, services, supplies or operation of the House, including salaries of House Employees.

The House Committee, in consultation with the Treasurer, shall determine the equitable proportion of expense to be assessed for the use of the facilities of the House, which are approved by the Council for other than Academy activities.

(ii) *The Committee on Membership* shall consist of the President, *ex officio*, as Chairman, and eight Fellows, not members of the Council, one from each Class to be elected annually to serve for two years, except that in the initial election one additional Fellow shall be elected from each Class to serve for one year only. It shall have the duties designated to it in Chapter III.

(iii) *The Committee on Meetings* shall consist of the President as Chairman, the Secretary, *ex officio*, who shall be secretary of the committee, the four Vice-Presidents, *ex officiis*, and of four other Fellows, not members of the Council, one from each Class. It shall arrange for meetings of the Academy.

(iv) *The Committee on Finance* shall consist of the Treasurer, *ex officio*, as Chairman, and four other Fellows. It shall have general oversight of the investments of the Academy.

(v) *The Auditing Committee* shall consist of two Fellows who shall audit the accounts of the Treasurer with power to employ an expert and to approve his bill.

(vi) *The Committee on Publication* shall consist of the Editor as Chairman, *ex officio*, and four other Fellows, one from each Class. It shall have the authority and the responsibility of determining the contents and of effecting the printing of the Publications of the Academy as set forth in Chapter IX.

(vii) *The Permanent Science Fund Committee* shall consist of seven Fellows. It shall review all applications for grants addressed to it and shall from time to time recommend to the Council appropriate disbursements from the income received by the Academy from the Trustee of the Permanent Science Fund, for carrying out the purposes set forth in the Agreement and Declaration of Trust which governs the use of this Fund.

(viii) *The Rumford Committee* shall consist of seven Fellows. It shall invite applications for pecuniary assistance in support of researches in the fields of heat and light, including X rays, and it alone shall authorize the purchase of books, publications and apparatus at the charge of the income from the Rumford Fund. It shall biennially recommend to the Council a candidate for the reception of the Premium to be awarded in accordance with the Rumford trust, and shall generally see to the proper execution of this trust.

(ix) *The C. M. Warren Committee* shall consist of seven Fellows. It shall invite applications for pecuniary assistance from any person wishing to engage in research in any branch of chemistry and shall recommend to the Council such applications as seem to be worthy of aid, and such other disbursements from income of the C. M. Warren Fund as it deems appropriate to the advancement of research in chemistry.

(x) *The Amory Prize Committee* shall consist of seven Fellows. It shall consider persons eligible and recommend to the Council the award by the President and Fellows of the Amory Prize and a gold medal or other token of honor and merit for each septennium beginning with that which was concluded on November 10, 1933, and thereafter, said award being in recognition of an invention or other contribution in the medical field specified in and according to the terms of the bequest of Francis Amory.

ARTICLE 2. Each Standing Committee shall confine its recommendations and its expenditures to such sum in each fiscal year as shall have been notified to its Chairman by the Secretary of the Academy as appropriations voted by the Academy, or by the Treasurer as income available for its purposes.

ARTICLE 3. Each Standing Committee shall report to the Academy at the Annual Meeting its acts of the previous year.

See Chap. iii; chap. iv, art. 1, 3; chap. vi, art. 4; chap. vii, art. 1, 2, 4; chap. ix, art. 1, 2.

CHAPTER XII

MEETINGS, COMMUNICATIONS, AND AMENDMENTS

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May. Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation.

Special Meetings shall be called by the Secretary at the request of the President, of the Council, or of ten Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called.

The Council shall have authority, as occasion may demand, to arrange additional meetings and to cancel any of the statutory meetings, except that meetings for transacting business shall be held as required by the Statutes.

ARTICLE 2. Except as otherwise provided, twenty-five Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings. Eighteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3. Upon the request of the presiding officer or the Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4. Fellows may introduce guests at any of the literary or scientific meetings of the Academy.

ARTICLE 5. All amendments to the Statutes, whether proposed by Fellows or by the Council, shall be considered by the Council and reported with recommendations for action to the Academy. At a subsequent Stated Meeting, or at a Special Meeting called for the purpose, the notice for which in either case shall state this proposed amendment, the Academy shall act upon the amendment. Two-thirds of the Fellows present, in a meeting of not less than forty Fellows, must vote in the affirmative to enact the amendment.

See Chap. ii, art. 6, 10; chap. iii, art. 1, 2; chap. iv, art. 1, 3, 4, 5; chap. v, art. 1; chap. vi, art. 2, 3; chap. vii, art. 2, 5; chap. ix, art. 2; chap. x, art. 5; chap. xi, art. 1, 3.

CHARTER OF INCORPORATION

An Act to incorporate and establish a Society for the cultivation and promotion of Arts and Sciences. Granted May 4, 1780, by an Act of the Legislature of Massachusetts, and amended by the Acts of 1910, 1911, 1931, and 1947.

As the Arts and Sciences are the foundation and support of agriculture, manufactures, and commerce; as they are necessary to the wealth, peace, independence, and happiness of a people; as they essentially promote the honor and dignity of the government which patronizes them; and as they are most effectually cultivated and diffused through a State by the forming and incorporating of men of genius and learning into public societies for these beneficial purposes.

Be it therefore enacted by the Council and House of Representatives in General Court assembled and by the authority of the same, that [sixty-two persons][1] be, and they hereby are formed into, constituted, and made a body politic and corporate, by the name of THE AMERICAN ACADEMY OF ARTS AND SCIENCES, and that they, and their successors, and such other persons as shall be elected in the manner hereafter mentioned, shall be and continue a body politic and corporate, by the same name forever.

And be it further enacted by the authority aforesaid, that the Fellows of the said Academy may from time to time elect a President, one or more Vice-Presidents, one or more Secretaries, and such other officers of the said Academy as they shall judge necessary or convenient; and they shall have full power and authority from time to time to determine and establish the names, number, and duties of their several officers, and the tenure or estate they shall respectively have in their offices; and also to authorize and empower their President, or some other Fellow of the Academy, at their pleasure, to administer such oaths to such officers as they shall appoint and determine, for the well-ordering and good government of the said Academy, provided the same be not repugnant to the laws of this State.

And be it further enacted by the authority aforesaid, that the Fellows of the said Academy shall have one Common Seal, which they may make use of in whatsoever cause or business shall concern the Academy, or be relative to the end and design of its institution; and shall have power and authority from time to time to break, change, and renew the Common Seal, at their pleasure; and that they may sue and be

[1] For the names of the Fellows incorporated, see Memoirs, Vol. XI, Part I, pp. 33, 34.

sued, in all actions, real, personal, and mixed, and prosecute and defend the same unto final judgment and execution, by the name of the President and Fellows of the American Academy of Arts and Sciences.

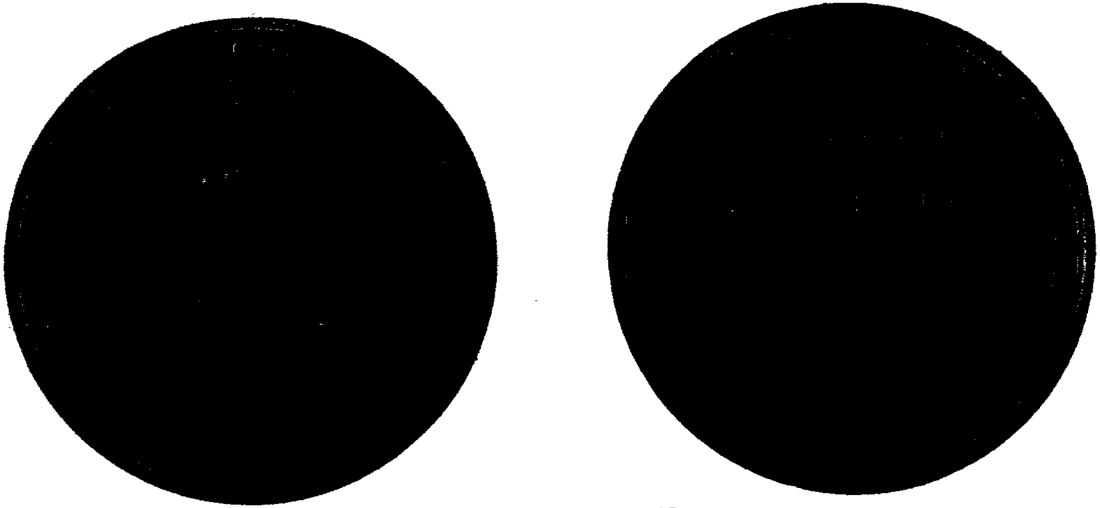
And be it further enacted by the authority aforesaid, that the Fellows of the said Academy may from time to time elect such persons to be Fellows thereof, as they shall judge proper, and that they shall have full power and authority from time to time to suspend, expel, or disfranchise any Fellow of the said Academy who shall by his conduct render himself unworthy of a place in that body, in the judgment of the Academy; and also to settle and establish the rules, forms, and conditions of election, suspension, expulsion, and disfranchisement.

And be it further enacted by the authority aforesaid, that the Fellows of the said Academy shall have full power and authority from time to time to make and enact such reasonable rules, orders, and bylaws, not repugnant to the laws of this State, as shall be necessary or convenient for the well-ordering and good government of the said Academy, and to annex reasonable pecuniary fines and penalties to the breach of them, not exceeding the sum of *twenty pounds*, to be sued for and recovered in any court of record within this State, in the name and for the use of the President and Fellows of the said Academy; and the same rules, orders, and bylaws to repeal at their pleasure; and also to settle and establish the times, places, and manner of convening the Fellows of the said Academy; and also to determine the number of Fellows which shall be present to constitute a meeting of the said Academy. *Provided*, that the Fellows of the said Academy shall meet twice in a year at the least; and that the place of their meeting shall never be more than thirty miles distant from the town of Boston.

And be it further enacted by the authority aforesaid, that the Fellows of the said Academy may, and shall forever hereafter, be deemed capable in the law, of having, holding, and taking in fee-simple, or any less estate, by gift, grant, devise or otherwise, any lands, tenements or other estate real and personal. *Provided*, that the said real estate shall not exceed in value the sum of *two hundred thousand dollars*, and the said personal estate shall not exceed in value the sum of *five hundred thousand dollars*, all the sums mentioned in the preceding section of this act to be valued in silver at the rate of *six shillings and eightpence* by the ounce. And the annual interest and income of the said real and personal estate, together with the fines and penalties aforesaid, shall be appropriated for premiums to encourage improvements and discoveries in agriculture, arts, and manufactures, or for other purposes consistent with the end and design of the institution of the said Academy as the Fellows thereof shall determine.

And be it further enacted by the authority aforesaid, that the end and design of the institution of the said Academy is, to promote and encourage the knowledge of the antiquities of America, and of the natural history of the country, and to determine the uses to which the various natural productions of the country may be applied; to promote and encourage medical discoveries; mathematical disquisitions; philosophical inquiries and experiments; astronomical, meteorological, and geographical observations; and improvements in agriculture, arts, manufactures, and commerce; and, in fine, to cultivate every art and science which may tend to advance the interest, honor, dignity, and happiness of a free, independent, and virtuous people.

And it is further enacted, that the place where the first meeting of the Fellows of the said Academy shall be held shall be the Philosophy Chamber in the University of Cambridge; and that the Honorable James Bowdoin, Esq., be, and he hereby is authorized and empowered to fix the time for holding the said meeting, and to notify the same to the Fellows of the Academy.



THE RUMFORD MEDAL

THE RUMFORD FUND RECORD

1. BENJAMIN THOMPSON, COUNT RUMFORD

This biographical account was written for the Rumford Committee by Professor Sanborn C. Brown of the Massachusetts Institute of Technology, who is a special student of Rumford.

Count Rumford presented a gift, in 1796, of $5,000 to the American Academy of Arts and Sciences, the interest of which was to be used for a medal to be given "to the author of the most important discovery or useful improvement . . . on Heat or on Light; the preference always being given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind". In specifying these conditions for his medal, Rumford epitomized his own successful scientific endeavors.

Benjamin Thompson was born in Woburn, Massachusetts, on March 26, 1753. His boyhood experience as a dry-goods clerk in Salem and Boston showed that his talents lay in other fields. The study of medicine seemed more promising, but he abandoned this to become a schoolteacher in Bradford, Massachusetts. Here he began a serious study of science under the guidance of the Reverend Samuel Williams, who was later to become professor of natural philosophy at Harvard and an eminent Fellow of the American Academy of Arts and Sciences. His marriage to a rich widow in Concord, New Hampshire, gave him leisure for philosophical writing. Having embraced the Tory cause in the Revolution, he left for England in 1776 to spend his life as a scientist soldier of fortune. His early papers, which reflect his professional interests, concerned investigations of gunpowder, the designs of warships, cannon, and artillery. While Thompson was Under Secretary for the Northern Department, his patron, Lord George Germain, gave him the freedom and facilities for carrying on his experiments.

At the close of the American Revolution, in which Thompson rose to the rank of Lieutenant Colonel in command of the King's American Dragoons against his countrymen on Long Island, he was retired on half pay from the British Army. He was knighted by George III, but spent his most productive years in the service of the Elector of Bavaria. A prolific investigator, he wrote over fifty papers, many of which appeared at different times in English, German and French. Of these papers, thirty were on the subject of heat, six on light, and seven on the formation and operation of scientific and charitable institutions. His works were drawn together by the Academy in

1870 in the four-volume collection, "The Complete Works of Count Rumford".

Rumford is best known for his intensive attacks on caloric, and he was one of the first successful advocates of the energy theory of heat. His classic cannon-boring experiment, carried out while he was Inspector General of Artillery for the Elector of Bavaria, was one of a long series of studies extending over thirty years of his life. He carried out a large number of experiments to refute the caloric arguments, including the thermal expansion of water below 41°F., conduction of heat through a vacuum, evaporation and sublimation, radiation and absorption of heat from rough and smooth surfaces, the spontaneous mixtures of liquids at constant temperature, the weight of heat, and various investigations to show heat from mechanical work.

"Useful improvements . . . to promote the good of mankind" were fully as significant to Count Rumford as "important discovery." In the field of heat, he wrote nine papers concerning practical applications of his theoretical studies. Having discovered the existence of convection currents, he designed the modern fireplace, introducing the smoke shelf, the throat, and the sloping back and bevelled walls to project the heat into the room. He designed cooking stoves from which the modern kitchen range is directly descended. He introduced ovens for roasting, a pressure cooker, the modern double boiler, and the use of steam heat for heating rooms. He was always very proud of the fact that he never patented any of his many inventions, but published detailed descriptions of his innovations for all to copy.

In 1799 Thompson, who by then had been made a Count of the Holy Roman Empire by the grateful Elector of Bavaria, was sent to England as a Bavarian minister. George III refused to accept one of his own subjects as a foreign representative, and Rumford occupied his enforced leisure by setting up the Royal Institution of Great Britain. Before he left this project, he assured the success of the Royal Institution by hiring for lecturers such men as Humphrey Davy, Thomas Young, and others of their caliber.

Count Rumford spent the last years of his life in the vicinity of Paris. It was here that he married the wealthy widow of Lavoisier, a violently unhappy match which lasted but a few years. It was here also that he found time to publish detailed accounts of improved lamps and illumination.

Rumford's early work on light was mostly theoretical. He wrote papers on the intensity of light from luminous bodies, inventing for the purpose the shadow photometer which still bears his name. He studied colored shadows and the harmony of colors, and showed that

the photo-chemical effect of silver salts was due to light and not to heat. Rumford introduced a standard candle as a measure of luminous intensity, whose specifications have been changed less than 15 per cent in the intervening 140 years.

Count Rumford died at Auteuil, outside of Paris, on August 21, 1814. In his will he left a considerable bequest to Harvard College to set up a Rumford Professorship of the Physical and Mathematical Sciences as applied to the Useful Arts. This bequest is by no means the only memorial to Rumford's active interest in stimulating scientific endeavor. He founded the Royal Institution, gave his entire library on military science to the United States Military Academy whose directorship he had once been offered, and made identical gifts for Rumford medals to the Royal Society of London and the American Academy of Arts and Sciences.

2. THE RUMFORD FUND

This account of the Rumford Fund was prepared for the Committee by Professor Sanborn C. Brown of the Massachusetts Institute of Technology.

Count Rumford's donation of $5,000 was announced in a letter to the Honorable John Adams, President of the American Academy of Arts and Sciences, written in July, 1796. In this letter, Rumford stipulated "that the interest . . . may be . . . given once every second year, as a premium, to the author of the most important discovery or useful improvement, which shall be made and published by printing, or in any way made known to the public, in any part of the Continent of America, or in any of the American Islands during the preceding two years, on Heat, or on Light. . . . If during any term of two years, reckoning from the last adjudication . . . no new discovery or improvements should be made in any part of America, relative to either of the subjects in question (Heat or Light), which, in the opinion of the Academy shall be of sufficient importance to deserve this Premium, in that case it is my desire that the Premium may not be given, but that the value of it may be reserved, and by laying out in the purchase of additional stock in the American funds may be applied to augment the capital of this Premium".

Although the Academy was delighted to accept this gift, it soon became apparent that the restrictions on the gift were too severe. By 1829, no Rumford medal had been given, and a committee of the Academy was formed to look into the matter. As a result of their study, the Academy applied for relief from the conditions of the gift, to the Supreme Court of Massachusetts. The case was argued on the 18th of May, 1832, before Judge Shaw. The Academy's case was pre-

sented by the President, Nathaniel Bowditch: "So it is, may it please your Honors, that since the receipt of the said donation, there has not come to the knowledge of your orators, any discovery or improvement respecting either light or heat, . . . which has within two years after the same was so made public seemed to your orators of sufficient importance to deserve said premiums . . . and your orators have from time to time . . . received the income of said duration, and added the same to the principal, without awarding any premiums therefrom, until said fund has now become of the amount of about $20,000 . . . And your orators further show to your Honors, that the said instructions and directions expressed in the said letter of said donor cannot . . . be strictly and literally complied with and performed; because discoveries . . . of sufficient importance . . . cannot be made as often as once in two years, and because it is not often practicable within the space of two years after the discoveries or improvements are first made public to determine whether they are of sufficient importance to deserve said premiums or not; and because . . . the amount of the income thereof to be awarded becomes too large for the proper reward of scientific researches, which should consist rather in the honor than in the pecuniary value of the premium . . .".

The opinion, delivered by Judge Shaw, relieved the Academy of the impractical features while at the same time fully retaining the spirit of Count Rumford's gift. This opinion, delivered on May 18, 1832, stipulated the conditions under which the Rumford Fund still operates:

"It is therefore by the court ordered . . . that the plaintiffs be, . . . empowered to make from the income of said fund, as it now exists, at any annual meeting of the Academy, instead of biennially, as directed by the said Benjamin Count Rumford, award of a gold and silver medal . . . as a premium to the author of any important discovery or useful improvement on heat or on light . . . in any part of the Continent of America, or any of the American Islands. . . .

"And it is further ordered, . . . that the plaintiffs may appropriate from time to time, as the same can advantageously be done, the residue of the income of said fund hereafter to be received . . . to the purchase of such books and papers and philosophical apparatus (to be the property of said Academy) and in making such publications, or procuring such lectures, experiments, or investigations, as shall in their opinion best facilitate and encourage the making of discoveries and improvements which may merit the premium so as aforesaid to be by them awarded . . .".

The Academy's case was complicated by a claim which Harvard College pressed for the accrued interest. When Count Rumford executed his will in France in 1812, he bequeathed the whole residue of his property to the President and Fellows of Harvard College, whom he appointed his residuary legatees for the purpose of setting up the Rumford Professorship of the Application of Science to the Useful Arts.

Harvard's case was put before Judge Shaw by its President, Josiah Quincy. "Inasmuch as the said objects and purposes for which said Benjamin Count Rumford founded the . . . professorship do include the objects specified in his said donation made to the complainants . . . and inasmuch as the said Benjamin Count Rumford has, in and by his last will and the codicil thereto, expressed and manifested his wish and intention that all his estate not otherwise disposed of should be applied to the institution and maintenance of the said professorship, they do humbly insist that if the said fund and accumulation thereof . . . cannot be appropriated and applied in the hands of the said complainants . . . the same . . . ought to be decreed to be paid over to these defendants as residuary legatees to said Count Rumford for the use of said Rumford Professorship . . . " The judge sharply rejected the college's plea.

At the close of the last fiscal year of the Academy (1948–49) the Rumford Fund amounted to $86,819.29, the income for that year having been $4,238.29.

Simultaneous with his gift to the American Academy of Arts and Sciences, Rumford presented £1,000 to the Royal Society of London under identical conditions. The Royal Society also found some difficulty with the conditions of the donation, but by correspondence with Count Rumford and finally placing him on their committee, they arrived at workable conditions so that by 1802 they awarded the first Rumford medal to Count Rumford himself. The Rumford Fund of the Royal Society has been devoted solely to the award of the premium according to the original provisions of that trust.

3. THE RUMFORD COMMITTEE

A standing committee of the Academy known as the Rumford Committee, consisting of seven Fellows, is charged with the supervision of the trust created by Count Rumford, and considers all applications and claims for the Rumford Premium, and all applications made for grants from the income of the fund in aid of research or for other purposes.

The Rumford Committee was first constituted a standing committee in 1833. Its members were nominated annually by the President of the Academy until 1863, since which time they have been chosen in the same manner as the other officers.

The following is a list of those who have been members of the Committee.

MEMBERS OF THE RUMFORD COMMITTEE

1833–1949

1833–1838, Nathaniel Bowditch
1833–1837, Francis C. Gray
1833–1848, Daniel Treadwell
1833–1846, Jacob Bigelow
1833–1849, John Ware
1837–1846, John Pickering
1838–1839, James Jackson
1839–1840, Benjamin Peirce
1840–1843, George B. Emerson
1843–1849, Benjamin Peirce
1846–1850, Francis C. Lowell
1846–1847, James Hayward
1847–1868, Joseph Lovering
1848–1863, Eben N. Horsford
1849–1863, Daniel Treadwell
1849–1878, Morrill Wyman
1850–1862, Henry L. Eustis
1862–1871, Joseph Winlock
1863–1869, William B. Rogers
1863–1864, Charles W. Eliot
1863–1864, Theophilus Parsons
1863–1866, Cyrus M. Warren
1864–1894, Wolcott Gibbs
1864–1871, Francis H. Storer
1866–1877, Josiah P. Cooke
1868–1878, James B. Francis
1869–1890, Edward C. Pickering
1871–1885, John M. Ordway
1871–1880, Stephen P. Ruggles
1877–1897, John Trowbridge
1878–1892, Josiah P. Cooke
1878–1892, Joseph Lovering
1880–1891, George B. Clark
1885–1915, Erasmus D. Leavitt
1890–1896, Benjamin O. Peirce
1892–1919, Edward C. Pickering
1892–1906, Amos E. Dolbear
1892–1921, Charles R. Cross
1894–1896, Benjamin A. Gould
1896–1923, Arthur G. Webster
1897–1902, Thomas C. Mendenhall
1897–1911, Theodore W. Richards
1902–1937, Elihu Thomson
1906–1923, Louis Bell
1911–1920, Arthur A. Noyes
1915–1924, Theodore Lyman
1919– Percy W. Bridgman
1920–1947, Harry M. Goodwin
1922–1939, Charles L. Norton
1924–1936, Arthur E. Kennelly
1924– Harlow Shapley
1924–1930, Frederick A. Saunders
1930–1944, Norton A. Kent
1936–1944, George W. Pierce
1937– George R. Harrison
1940–1946, Robert B. Lindsay
1944– Francis O. Schmitt
1945– Edwin H. Land
1946– Joseph H. Keenan
1947– Arthur C. Hardy

RUMFORD COMMITTEE CHAIRMEN

1833–1949

1833–1838, Nathaniel Bowditch	1876–1878, Morrill Wyman
1838–1839, James Jackson	1878–1892, Joseph Lovering
1839–1846, John Pickering	1892–1897, John Trowbridge
1846–1848, Daniel Treadwell	1897–1921, Charles R. Cross
1848–1863, Eben N. Horsford	1921–1924, Theodore Lyman
1863–1868, Joseph Lovering	1924–1936, Arthur E. Kennelly
1868–1871, Joseph Winlock	1936–1939, Harlow Shapley
1871–1876, Josiah P. Cooke	1939–1944, Norton A. Kent

1944– , Harlow Shapley

4. THE RUMFORD PREMIUM

The Rumford Premium is awarded by the Academy upon the recommendation of the Rumford Committee. It has been given to the following persons and on the ground stated.

AWARDS OF THE RUMFORD PREMIUM OF THE AMERICAN ACADEMY

1839. Robert Hare, of Philadelphia, for his invention of the compound or oxyhydrogen blowpipe.

1862. John Ericsson, of New York, for his improvements in the management of heat, particularly as shown in his caloric engine of 1858.

1865. Daniel Treadwell, of Cambridge, for improvements in the management of heat, embodied in his investigations and inventions relating to the construction of cannon of large calibre, and of great strength and endurance.

1866. Alvan Clark, of Cambridge, for his improvements in the manufacture of refracting telescopes, as exhibited in his method of local correction.

1869. George Henry Corliss, of Providence, for his improvement in the steam-engine.

1871. Joseph Harrison, Jr., of Philadelphia, for his mode of constructing steam-boilers, by which great safety has been secured.

1873. Lewis Morris Rutherfurd, of New York, for his improvements in the processes and methods of astronomical photography.

1875. John William Draper, of New York, for his researches on radiant energy.

1880. Josiah Willard Gibbs, of New Haven, for his researches in thermodynamics.

1883. Henry Augustus Rowland, of Baltimore, for his researches in light and heat.

1886. Samuel Pierpont Langley, of Allegheny, for his researches in radiant energy.

1888. Albert Abraham Michelson, of Cleveland, for his determination of the velocity of light, for his researches upon the motion of the luminiferous ether, and for his work on the absolute determination of the wave lengths of light.

1891. Edward Charles Pickering, of Cambridge, for his work on the photometry of the stars and upon stellar spectra.

1895. Thomas Alva Edison, of Orange, N. J., for his investigations in electric lighting.

1898. James Edward Keeler, of Allegheny, for his application of the spectroscope to astronomical problems, and especially for his investigations of the proper motions of the nebulae, and the physical constitution of the rings of the planet Saturn, by the use of that instrument.

1899. Charles Francis Brush, of Cleveland, for the practical development of electric arc-lighting.

1900. Carl Barus, of Providence, for his various researches in heat.

1901. Elihu Thomson, of Lynn, for his inventions in electric welding and lighting.

1902. George Ellery Hale, of Chicago, for his investigations in solar and stellar physics and in particular for the invention and perfection of the spectro-heliograph.

1904. Ernest Fox Nichols, of New York, for his researches on radiation, particularly on the pressure due to radiation, the heat of the stars, and the infra-red spectrum.

1907. Edward Goodrich Acheson, of Niagara Falls, for the application of heat in the electric furnace to the industrial production of carborundum, graphite, and other new and useful substances.

1909. Robert Williams Wood, of Baltimore, for his discoveries in light, and particularly for his researches on the optical properties of sodium and other metallic vapors.

1910. Charles Gordon Curtis, of New York, for his improvements in the utilization of heat as work in the steam turbine.

1911. James Mason Crafts, of Boston, for his researches in high-temperature thermometry and the exact determination of new fixed points on the thermometric scale.

1912. Frederic Eugene Ives, of Woodcliff-on-Hudson, for his optical inventions, particularly in color photography and photo-engraving.

1913. Joel Stebbins, of Urbana, for his development of the selenium photometer and its application to astronomical problems.

1914. William David Coolidge, of Schenectady, for his invention of ductile tungsten and its application in the production of radiation.

1915. Charles Greeley Abbot, of Washington, D. C., for his researches on solar radiation.

1917. Percy Williams Bridgman, of Cambridge, for his thermodynamical researches at extremely high pressures.

1918. Theodore Lyman, of Cambridge, for his researches on light of very short wave length.

1920. Irving Langmuir, of Schenectady, for his researches in thermionic and allied phenomena.

1925. Henry Norris Russell, of Princeton, for his researches in stellar radiation.

1926. Arthur Holly Compton, of Chicago, for his researches in Röntgen rays.

1928. Edward Leamington Nichols, of Ithaca, for his researches in spectrophotometry.

1930. John Stanley Plaskett, of Victoria, B. C., for his stellar spectrographic researches.

1931. Karl Taylor Compton, of Cambridge, for researches in thermionics and spectroscopy.

1933. Harlow Shapley, of Cambridge, for researches on the luminosity of stars and galaxies.

1937. William Weber Coblentz, of Washington, pioneer in the technology and measurement of heat and light.

1939. George Russell Harrison, of Belmont, Mass., for his improvements in spectroscopic technique.

1941. Vladimir Kosma Zworykin, of Princeton, for his invention of the iconoscope and other television devices.

1943. Charles Edward Kenneth Mees, of Rochester, for his contributions to the science of photography.

1945. Edwin Herbert Land, of Cambridge, for his new applications in polarized light and photography.

1947. *Edmund Newton Harvey, of Princeton, for his fundamental investigations of the nature of bioluminescence.*

1949. Ira Sprague Bowen, of Pasadena, for his solution of the mystery of nebulium and for other outstanding work in spectroscopy.

AWARDS OF THE RUMFORD PREMIUM OF THE ROYAL SOCIETY

1802. Benjamin Count Rumford. For his various discoveries respecting light and heat.

1804. John Leslie. Experiments on heat.

1806. William Murdock. Publication on the employment of gas from coal for the purpose of illumination.

1810. Étienne Louis Malus. Discovery of certain properties of reflected light.

1814. William Charles Wells. Essay on dew.

1816. Humphry Davy. Papers on combustion and flame.

1818. David Brewster. Discoveries relating to the polarization of light.

1824. Augustin Jean Fresnel. Development of the undulatory theory, as applied to the phenomena of polarized light. and *various important discoveries in physical optics.*

1832. John Frederic Daniell. Experiments with a new register pyrometer for measuring the expansion of solids.

1834. Macedonio Melloni. Discoveries relative to radiant heat.

1838. James David Forbes. Experiments on the polarization of heat.

1840. Jean Baptiste Biot. Researches in and connected with the circular polarization of light.

1842. Henry Fox Talbot. Discoveries and improvements in photography.

1846. Michael Faraday. Discovery of the optical phenomena developed by the action of magnets and electric currents in certain transparent media.

1848. Henri Victor Regnault. Experiments on expansion and density of air, different gases, and mercury.

1850. François Jean Dominique Arago. Experimental investigation on polarized light.

1852. George Gabriel Stokes. On the change of refrangibility of light.

1854. NEIL ARNOTT. A new smoke-consuming and fuel-saving fireplace.

1856. LOUIS PASTEUR. *Discovery of the nature of racemic acid, and its relations to polarized light.*

1858. JULES CÉLESTIN JAMIN. Various experimental researches on light.

1860. JAMES CLERK MAXWELL. Researches on the composition of colors, and other optical papers.

1862. GUSTAV ROBERT KIRCHHOFF. Researches on the fixed lines of the solar spectrum, and on the inversion of the bright lines in the spectra of artificial light.

1864. JOHN TYNDALL. Researches on the absorption and radiation of heat by gases and vapors.

1866. ARMAND HIPPOLYTE LOUIS FIZEAU. Optical researches and investigations into the effect of heat on the refractive power of transparent bodies.

1868. BALFOUR STEWART. Researches on the qualitative as well as quantitative relations between the powers of emission and absorption of bodies for heat and light.

1870. ALFRED OLIVIER DES CLOIZEAUX. Researches in mineralogical optics.

1872. ANDERS JONAS ÅNGSTRÖM. Researches on spectral analysis.

1874. JOSEPH NORMAN LOCKYER. Spectroscopic researches on the sun and on the chemical elements.

1876. PIERRE JULES CÉSAR JANSSEN. Researches on the radiation and absorption of light, carried on chiefly by means of the spectroscope.

1878. ALFRED CORNU. Optical researches, and especially his recent redetermination of the velocity of propagation of light.

1880. WILLIAM HUGGINS. Astronomical researches.

1882. WILLIAM DE WIVELESLIE ABNEY. Contributions to the advancement of the theory and practice of photography.

1884. TOBIAS ROBERT THALÉN. Spectroscopic researches.

1886. SAMUEL PIERPONT LANGLEY. Researches on the spectrum by means of the bolometer.

1888. PIETRO TACCHINI. Important and long-continued investigations which have largely advanced our knowledge of the physics of the sun.

1890. HEINRICH HERTZ. Work on electro-magnetic radiation.

1892. NILS CHRISTOFER DUNÉR. Astronomical observations.

1894. JAMES DEWAR. Researches at very high and very low temperatures, and on spectroscopic phenomena.

1896. PHILIPP LENARD AND WILHELM KONRAD RÖNTGEN. Researches on phenomena which occur outside a highly exhausted tube through which an electrical discharge is passing.

1898. OLIVER JOSEPH LODGE. Researches on radiation and on the relations between matter and ether.

1900. ANTOINE HENRI BECQUEREL. Discoveries in radiation proceeding from uranium.

1902. CHARLES ALGERNON PARSONS. Application of the steam *turbine to industrial purposes and its recent extension to* navigation.

1904. ERNEST RUTHERFORD. Researches on radio-activity, and particularly his discovery of the existence and properties of the gaseous emanations from radio-active bodies.

1906. HUGH LONGBOURNE CALLENDAR. Experimental work on heat.

1908. HENDRIK ANTOON LORENTZ. Investigations in optical and electrical science.

1910. HEINRICH RUBENS. Researches on radiations, especially of long wave lengths.

1912. KAMERLINGH ONNES. Researches at low temperatures.

1914. LORD RAYLEIGH. Investigations in thermodynamics and on radiation.

1916. WILLIAM HENRY BRAGG. Researches in X-ray radiation.

1918. CHARLES FABRY AND ALFRED PEROT. Contributions to optics.

1920. LORD RAYLEIGH. Researches into the properties of gases at high vacua.

1922. PIETER ZEEMAN. Researches in optics.

1924. CHARLES VERNON BOYS. Invention of the gas calorimeter.

1926. SIR ARTHUR SCHUSTER. Services to physical science, especially in the subjects of optics and terrestrial magnetism.

1928. FRIEDRICH PASCHEN. Contributions to the knowledge of spectra.

1930. PETER DEBYE. Work relating to specific heats and X-ray spectroscopy.

1932. FRITZ HABER. Outstanding importance of his work in physical chemistry, especially in the application of thermodynamics to chemical reactions.

1934. WANDER JOHANNES DE HAAS. Researches on the properties of bodies at low temperatures, and in particular his recent work on cooling by the use of adiabatic demagnetisation.

1936. Ernest John Coker. Researches on the use of polarized light for investigating directly the stresses in transparent models of engineering structures.

1938. Robert Williams Wood. Distinguished work and discoveries in many branches of physical optics.

1940. Karl Manne Georg Siegbahn. Pioneer work in high precision X-ray spectroscopy and its applications.

1942. Gordon Miller Bourne Dobson. Outstanding work on the physics of the upper air and its application to meteorology.

1944. Harry Ralph Ricardo. Important contributions to research on the internal combustion engine, which have greatly influenced the development of the various types.

1946. Sir Alfred Egerton. Leading part in the application of modern physical chemistry to many technological problems of pressing importance.

1948. Franz Eugen Simon. Outstanding contributions to the attainment of low temperatures and to the study of the properties of substances at temperatures near the absolute zero.

5. GRANTS FOR RESEARCH

Applications for aid from the Rumford Fund in furtherance of researches in heat or light may be sent to the Chairman of the Rumford Committee, American Academy of Arts and Sciences, 28 Newbury St., Boston 16, Massachusetts. Full statements should be made as to the object of the investigation for which aid is asked including expected duration of the project, the institutional support, the previous publications in this field by the applicant if any.

A report on the progress of the research for which a grant has been made should be submitted within a year of the making of the grant.

Prior to 1898 it was understood that, in general, papers embodying the results of researches aided by appropriation from the Rumford Fund should be originally published by the Academy. Since that date, however, the place of publication has been optional with the author. A list of these papers published by the Academy and elsewhere is to be found in the booklets entitled "The Rumford Fund" published by the Academy in 1905 and 1912.

All apparatus purchased wholly from appropriations from the Rumford Fund is the property of the Academy and is to be returned to it when the research in question is completed.

In view of the widening field of radiation and the importance of investigations of heat and light in many areas beyond physics, chemistry, engineering, and astronomy, the Rumford Fund Committee has in recent years ruled that cosmic rays, X rays, and radio waves should be considered within the interests of the Committee, and that researches in some fields of biology and geology also fall within the scope of the program.

GRANTS FROM THE RUMFORD FUND

1832–1862.	1.	Observatory at Cambridge. For telescope and other apparatus	$3776
	2.	Enoch Hale. For rain gauges and sundry expenses for experiments and investigations relating to the fall of rain	1697
1862.	3.	Philander Shaw. Experiments relating to air-engines	600
1863.	4.	Ogden N. Rood. Physical relations of iodized plate to light. (Appropriation subsequently transferred to another research, viz., photometry, 7.)	300
1864.	5.	Wolcott Gibbs. For purchase of a Meyerstein spectrometer and Regnault's apparatus for measuring vapor tension	600
1865.	6.	Josiah P. Cooke, Jr. For purchase of glass prisms to be used in an investigation of metallic spectra. (These prisms were purchased from the Academy by Professor Cooke in 1871.)	200
1866.	7.	Ogden N. Rood. Photometry. (Appropriation 4, for relations of iodized plate to light, $300, transferred to this purpose.)	
1867.	8.	Wolcott Gibbs. For repairing Meyerstein spectrometer belonging to the Academy. (Additional to 5.)	100
1869.	9.	Joseph Winlock. For purchase of spectroscopic instruments for observations of the solar eclipse of August, 1869	300
1870.	10.	Benjamin Apthorp Gould. For photometric and spectroscopic apparatus for the Observatory at Cordova. (Apparatus subsequently purchased by the Argentine Government.)	500
1875.	11.	John Trowbridge. Improvement of magneto-electric machine and induction coil	500

1876.	12.	Henry A. Rowland. New determination of mechanical equivalent of heat	$600
	13.	Samuel P. Langley. Researches on radiant energy	600
1877.	14.	Benjamin O. Peirce, Jr. Investigation of the conduction of heat in the interior of bodies. ($60, only, called for.)	200
	15.	Edward C. Pickering. Atmospheric refraction	520
1878.	16.	Wolcott Gibbs, John Trowbridge, Edward C. Pickering. Experiments on photometry and polarimetry. (A small portion only of this appropriation was called for.)	500
	17.	Charles A. Young. In aid of observations on solar eclipse of July 29, 1878. (Appropriation not called for.)	300
	18.	Nathaniel S. Shaler. Investigation on loss of internal heat of earth in the neighborhood of Boston. (Appropriation not called for.)	200
	19.	William W. Jacques. Experiments on the distribution of heat in the spectrum	100
	20.	Wolcott Gibbs, Edward C. Pickering, John Trowbridge. Determination of indices of refraction. (A small portion only of this appropriation was called for.)	500
1879.	21.	John Trowbridge. Heat developed by magnetization and demagnitization of magnetic metals	200
	22.	William W. Jacques. Radiation at high temperatures. (Additional to 19.)	200
	23.	William A. Rogers. To procure a metric standard of length	350
1880.	24.	Silas W. Holman. Viscosity of gases	250
	25.	Wolcott Gibbs. Construction of dynamoelectric machine of a new plan	150
	26.	Samuel P. Langley. Distribution of heat in diffraction spectrum. (Additional to 13.)	300
1882.	27.	Edward C. Pickering. Stellar photography, with a view of obtaining a method of estimating the brightness of stars	500
	28.	John Trowbridge. Thomson effect and allied subjects	250
1883.	29.	John Trowbridge. Addition to last preceding appropriation	100

1883.	30.	Frank N. Cole. Experiments on Maxwell's theory of light	$50
1884.	31.	Rumford Committee. For purchase of Rowland grating	40
	32.	William H. Pickering. Experiments in photography	200
	33.	John Trowbridge, Edward C. Pickering, Charles R. Cross. Experiments on standard of light	300
	34.	Edward C. Pickering. Photometry. (Additional to 27.)	200
	35.	William A. Rogers. Production of constant temperatures	100
	36.	John Trowbridge. Effect of changes of temperature on magnetism	100
1885.	37.	William A. Rogers. For construction of constant temperature room. (Additional to 35.)	82
	38.	Edward C. Pickering. Photometry. (Additional to 34.)	300
	39.	William H. Pickering. Photography and new standard of light. (Additional to 32.)	300
1886.	40.	William H. Pickering. Observations of solar corona, eclipse of August, 1886	500
	41.	Henry P. Bowditch. Calorimetric observations on the heat of the human body. ($100, only, called for.)	500
	42.	John Trowbridge. Standard of light. (Appropriation subsequently transferred to another research, viz., radiant energy, 44.)	250
	43.	Charles R. Cross. Thermoelectric effect in Munich-shunt method. (Appropriation not called for.)	75
1887.	44.	John Trowbridge. Investigations on radiant energy. (Appropriation 42, for standard of light, $250, transferred to this purpose.)	
	45.	Charles R. Cross and Silas W. Holman. Thermometry	250
	46.	Erasmus D. Leavitt, Jr. Investigations upon a pyrometer. (Appropriation not called for.)	250
	47.	John Trowbridge. Metallic spectra	250
1888.	48.	John Trowbridge. Metallic spectra. (Additional to 47.)	500

1888.	49.	William H. Pickering. For observations on solar eclipse of Jan., 1889	$500
1889.	50.	Charles C. Hutchins. Investigation on lunar radiation	250
	51.	Edwin H. Hall. Investigations on cylinder temperature	100
	52.	Henry A. Rowland. Metallic spectra	500
1890.	53.	Edwin H. Hall. Investigations on cylinder temperature. (Additional to 51.)	100
	54.	Benjamin O. Peirce. Temperature changes in interior of solids. (Appropriation not called for.)	200
1892.	55.	Daniel W. Shea. Velocity of light in magnetic field	250
	56.	Benjamin O. Peirce. Propagation of heat within certain solid bodies. (Reappropriation of 54.)	200
	57.	Henry A. Rowland. Investigations on solar spectrum. (Additional to 52.)	250
1893.	58.	William A. Rogers. Investigation on the pulsation of thermometers	175
	59.	William H. Pickering. Observations in Arizona on transparency and steadiness of the air and on the changes in temperature on the planet Mars. (Appropriation not called for.)	500
1894.	60.	Frank A. Laws. Thermal conductivity of metals.	300
	61.	Edward L. Nichols. Radiation from carbon at different temperatures	250
1895.	62.	Edwin H. Hall. Thermal conductivity of metals.	250
	63.	Arthur G. Webster. Velocity of electric waves	250
	64.	Benjamin O. Peirce. Thermal conductivities of poor conductors. (Additional to 56.)	250
1896.	65.	Henry Crew. Electric, chemical, and thermal effects of electric arc	400
	66.	Robert O. King. Thomson effect in metals	100
1897.	67.	Arthur G. Webster. Velocity of light. (Appropriation not called for.)	500
	68.	George E. Hale. For the construction of spectroheliograph	400
	69.	Arthur G. Webster. For the construction of revolving mirror. (Additional to 67. Appropriation returned.)	250
	70.	Arthur G. Webster and Robert R. Tatnall. The Zeeman effect. (Appropriation not called for.)	100

1898.	71.	Wallace C. Sabine. Researches on ultraviolet radiation	$400
	72.	Albert A. Michelson. New form of diffraction grating. (Echelon spectroscope.)	500
	73.	Theodore W. Richards. For the construction of a microkinetoscope, to be applied to a study of the birth and growth of crystals	200
1899.	74.	Wallace C. Sabine. Further researches on ultraviolet wave length. (Additional to 71.)	200
	75.	Henry Crew. Spectrum of the electric arc. (Additional to 65.)	200
	76.	Arthur G. Webster. Distribution of energy in various spectra studied by means of the Michelson interferometer and the radiometer. (Appropriation not called for.)	200
	77.	Edwin B. Frost. To aid in the construction of a spectrograph especially designed for the measurement of stellar velocities in the line of sight	500
1900.	78.	Edward C. Pickering. For constructing a new type of photometer to be used in an investigation on the brightness of faint stars, to be carried out by co-operation with certain observatories possessing large telescopes. (Additional to 38.)	500
	79.	Theodore W. Richards. Transition temperatures of crystallized salts	100
	80.	Arthur L. Clark. Molecular properties of vapors in the neighborhood of the critical point	250
	81.	Charles E. Mendenhall. Investigations on a hollow bolometer. ($100 only, called for.)	200
	82.	George E. Hale. Application of the radiometer to the study of the infrared spectrum of the chromosphere	500
	83.	Arthur A. Noyes. Effect of high temperatures on the electrical conductivity of salt solutions	300
1901.	84.	Theodore W. Richards. Research on the expansion of gases	500
	85.	Henry Crew. Order of appearance of the different lines of the spark spectrum. (Additional to 75.)	100
	86.	Robert W. Wood. Anomalous dispersion of sodium vapor	350
	87.	Arthur G. Webster. For purchase of fluorite plates	65

1902.	88.	Ernest F. Nichols. For the purchase of a spectrometer, in furtherance of a research on resonance in connection with heat radiations	$300
	89.	Theodore W. Richards. For the construction of a mercurial compression pump to be used in a research on the Joule-Thomson effect. (Appropriation subsequently transferred to another research, viz., the experimental study of chemical thermodynamics, 92.)	750
	90.	Arthur A. Noyes. Effect of high temperatures on the electrical conductivity of aqueous solutions (Additional to 83.)	300
	91.	Ralph S. Minor. Dispersion and absorption of substances for ultraviolet radiation . .	150
1903.	92.	Theodore W. Richards. Experimental study of chemical thermodynamics. (Appropriation 89 for compression pump, $750, transferred to this purpose.)	
	93.	Sidney D. Townley. For the construction of a stellar photometer	100
	94.	Edwin B. Frost. For the construction of a special lens for use in connection with the stellar spectrograph of the Yerkes Observatory for the study of radial velocities of faint stars. (Additional to 77.)	200
	95.	Ernest F. Nichols and Gordon F. Hull. In aid of the investigation of the relative motion of the earth and the ether by the method of "Fizeau's polarization experiment." (Appropriation transferred to another research, viz., effect of motion of earth on intensity of radiation, 98.) .	250
	96.	George E. Hale. For the purchase of a Rowland concave diffraction grating to be used in the photographic study of the brighter stars . .	300
	97.	Edward C. Pickering. For the construction of two stellar photometers to be placed at the disposal of the Rumford Committee. (Additional to 78.) .	150
	98.	Ernest F. Nichols and Gordon F. Hull. Effect of the motion of the earth on the intensity of radiation. (Appropriation 95 for Fizeau's polarization experiment, $250, transferred to this purpose.)	

1903.	99.	Frederic L. Bishop. Thermal conductivity of lead	$75
	100.	Frederick A. Saunders. Characteristics of spectra produced under varying conditions	200
	101.	William J. Humphreys. Shift of spectrum lines due to pressure	300
	102.	Norton A. Kent. Circuit conditions influencing electric spark lines	250
	103.	Edward W. Morley. Nature and effects of ether drift	500
1904.	104.	John A. Dunne. Fluctuations in solar activity as evinced by changes in the difference between maximum and minimum temperatures	200
	105.	Carl Barus. Optical method of study of radio-actively produced condensation nuclei. (Appropriation not called for.)	200
	106.	Dewitt B. Brace. Double refraction in gases in an electrical field	200
	107.	Robert W. Wood. Optical and other physical properties of sodium vapor. (Additional to 86.)	350
	108.	Norton A. Kent. (Additional to 102.) Circuit conditions influencing electric spark lines	100
	109.	Arthur L. Clark. Molecular properties of vapors in the neighborhood of the critical point. (Additional to 80.)	150
1905.	110.	Dewitt B. Brace. Double refraction in gases in an electrical field. (Additional to 106.)	200
	111.	Charles B. Thwing. Thermoelectric power of metals and alloys	150
	112.	Harry W. Morse. Fluorescence	500
	113.	John Trowbridge. Electric double refraction of light	200
	114.	Edwin H. Hall. Thermal and thermoelectric properties of iron and other metals. (Additional to 62.)	200
	115.	Arthur B. Lamb. Specific heat of salt solutions	200
	116.	John A. Parkhurst. For the purchase of a Hartmann photometer	225
	117.	Charles B. Thwing. Thermoelectric power of metals. (Additional to 111.)	400
1906.	118.	Edwin H. Hall. Thermoelectric properties of metals. (Additional to 114.)	100

1906.	119. Frederick E. Kester. Joule-Thomson effect in gases	$50
	120. Edwin H. Hall. Thermoelectric properties of metals. (Additional to 118.)	25
	121. Sidney D. Townley. Appropriation of $100 for a stellar photometer, 93, returned.	
	122. Arthur A. Noyes. For the construction of a calorimeter for the determination of heats of reaction at high temperatures. (Additional to 90.).	300
	123. Robert W. Wood. For the purchase of quartz mercury lamps. (Additional to 107.)	200
	124. Norton A. Kent. Spectral lines. (Additional to 108.)	75
	125. Leonard R. Ingersoll. Kerr effect in the infra-red rays	200
	126. Frederick E. Kester. Thermal properties of gases flowing through porous plug. (Additional to 119.)	315
1907.	127. Harry W. Morse. Fluorescence. (Additional to 112.)	400
	128. Percy W. Bridgman. Optical and thermal properties of bodies under extreme pressures	400
	129. Percy W. Bridgman. Optical and thermal properties of bodies under extreme pressures. (Additional to 128.)	400
1908.	130. Lawrence J. Henderson. New method for the direct determination of physiological heats of reaction. (Balance of appropriation, $100, returned.)	200
	131. Joel Stebbins. Use of selenium in photometry	100
	132. Willard J. Fisher. Viscosity of gases. (Balance of appropriation, $41, subsequently transferred to Edward L. Nichols. See 175.)	100
	133. Norton A. Kent. For the purchase of a set of echelon plates. (Additional to 124.)	400
	134. Joel Stebbins. Use of selenium in stellar photometry. (Additional to 131.)	100
1909.	135. William W. Campbell. For the purchase of a Hartmann photometer to be used in the measurement of polarigraphic images of the solar corona	250
	136. Robert W. Wood. Optical properties of mercury vapor. (Additional to 123.)	150

1909.	137.	Martin A. Rosanoff. Fractional distillation of binary mixtures	$300
	138.	Charles E. Mendenhall. Free expansion of gases	300
	139.	William W. Campbell. For the purchase of certain parts of a quartz spectrograph	300
	140.	Martin A. Rosanoff. Fractional distillation of binary mixtures. (Additional to 137.)	200
	141.	Leonard R. Ingersoll. Optical constants of metals	300
	142.	Joel Stebbins. Researches with the selenium photometer. (Additional to 134.)	350
	143.	William W. Campbell. Polariscopic study of the solar corona by means of a Hartmann photometer. (Additional to 135.)	125
1910.	144.	Charles E. Mendenhall and Augustus Trowbridge. Influence of ether drift upon the intensity of radiation	250
	145.	Charles E. Mendenhall. Free expansion of gases. (Additional to 138.)	250
	146.	Frank W. Very. For the purchase of photographic glass plates of the spectrum by George Higgs	50
	147.	Maurice DeK. Thompson. The high temperature equilibrium of the system of materials employed industrially in the carbide process for the fixation of atmospheric nitrogen	100
	148.	Percy W. Bridgman. Thermal and optical properties of bodies under extreme pressures. (Additional to 129.)	400
	149.	Charles L. Norton. Thermal insulation	400
1911.	150.	Joel Stebbins. Researches with the selenium photometer. (Additional to 142.)	200
	151.	Martin A. Rosanoff. Fractional distillation of binary mixtures. (Additional to 140.)	300
	152.	Daniel F. Comstock. Possible effect of the motion of the source on the velocity of light	100
	153.	Gilbert N. Lewis. Free energy changes in chemical reactions	150
	154.	Robert W. Wood. Optical properties of vapors. (Additional to 136.)	150
	155.	Daniel F. Comstock. Possible effect of the motion of the source on the velocity of light. (Additional to 152.)	150

1911.	156.	Frank W. Very. Intensity of spectrum lines. (Additional to 146.)	$150
	157.	John Trowbridge. For research of Harvey C. Hayes on thermoelectricity	300
	158.	Robert W. Wood. Optical properties of vapors; long heat waves. (Additional to 154.)	150
	159.	Arthur L. Clark. Physical properties of vapors in the neighborhood of the critical point. (Additional to 109.)	250
1912.	160.	Gilbert N. Lewis. Free energy changes in chemical reactions. (Additional to 153.)	250
	161.	Norton A. Kent. Purchase of a lens for magneto-spectroscopic researches. (Additional to 133.)	375
	162.	Frederick A. Saunders. Spectroscopic studies in the ultraviolet. (Additional to 100.)	100
	163.	William O. Sawtelle. Spectra of light from oscillatory discharge	250
	164.	George W. Ritchey. Construction of reflecting telescope employing mirrors with new forms of curves	500
1913.	165.	Edward L. Nichols. For research of W. P. Roop on effect of temperature on the magnetic susceptibility of gases	250
	166.	Frederick G. Keyes. For payment of computation expenses of thermodynamic tables for ammonia	300
	167.	In aid of publication of Marie's Annual International Tables of Constants (at the request of the Council) through Theodore W. Richards	100
	168.	Gilbert N. Lewis. Free energy changes in chemical reactions. (Additional to 160.)	300
	169.	William O. Sawtelle. Spectra of the light from spark in an oscillatory discharge. (Additional to 163.)	300
	170.	Harvey N. Davis. Thermodynamical researches	200
	171.	Louis V. King. To defray expenses of computation for research on scattering and absorption of solar radiation in the earth's atmosphere	250
1914.	172.	Alpheus W. Smith. Hall and Nernst effects in the rare metals	100
	173.	Charles G. Abbot. Applications of solar heat to domestic purposes	150

1914.	174.	Percy W. Bridgman. Thermodynamical researches at high pressures. (Additional to 148.)	$250
	175.	Edward L. Nichols. Hall effect and allied phenomena in tellurium and selenium. (Balances of 132 and 165, $282, transferred to this Research.)	
	176.	Percy W. Bridgman. Thermal effects of high pressures. (Additional to 174.)	150
	177.	Frederick A. Saunders. On the spectra of metallic vapors. (Additional to 162.)	100
	178.	Frederic Palmer, Jr. Properties of light of extremely short wave length	200
	179.	*Henry Crew. Specific heat of liquids*	200
	180.	Charles A. Kraus. Solutions in liquid ammonia; for purchase of a refrigerating apparatus	300
	181.	Herbert P. Hollnagel. Extreme infrared spectrum; for purchase of motor-generator	300
1915.	182.	Joel Stebbins. Research with improved photoelectric-cell photometer upon variable stars. (Additional to 150.)	140
	183.	Farrington Daniels. Specific heats; for purchase of calorimetric apparatus	330
	184.	Raymond T. Birge. Comparator for spectroscopic researches	200
	185.	Percy W. Bridgman. Thermal phenomena at high pressures. (Additional to 176.)	400
	186.	Arthur L. Clark. Physical properties of vapors near critical point. (Additional to 159.)	300
	187.	Gilbert N. Lewis. Free energy. (Additional to 168.)	300
1916.	188.	Harrison M. Randall. Infrared spectrum. (For salary of assistant.)	200
	189.	Raymond T. Birge. For purchase of comparator. (Additional to 184.)	175
	190.	Louis V. King. Molecular constants of gases from 25° K to 1273° K. (Research discontinued, appropriation returned.)	250
	191.	Frederic Palmer, Jr. Light of extremely short wave length. (Additional to 178.)	100
	192.	Robert A. Millikan. Photoelectric properties of metals in extreme vacua	500
	193.	John A. Parkhurst. Photometric scale of stellar magnitudes	300

1916.	194.	Everett T. King. Color of pigments	$25
	195.	Edward Kremers. Chemical action of light on organic compounds	300
1917.	196.	Floyd K. Richtmyer. Optical properties of thin films	500
	197.	Norton A. Kent. Spectral lines. (Additional to 161.)	400
	198.	Ancel St. John. Spectra of X rays	200
	199.	David L. Webster. Intensity of lines in X-ray spectra. (For payment of assistant.)	100
	200.	Frederic Palmer, Jr. Light of very short wave length. (Additional to 191.)	100
	201.	Bartholomew J. Spence. Color intensity photometer	75
	202.	Bartholomew J. Spence. New form of radiometer	150
	203.	Roswell C. Gibbs. Absorption of organic and other solutions for ultraviolet, visible and infrared rays	500
	204.	Wesley M. Baldwin. Sensitization of animal tissues for X rays by chemical means	125
	205.	Raymond T. Birge. Structure of series spectra. (Additional to 189.)	150
	206.	Ancel St. John. For the purchase of refrigerating machine for research on crystal structure by X rays	500
	207.	In aid of Publication of Marie's Annual International Tables of Constants, through Theodore W. Richards. (Additional to 167.)	250
1918.	208.	Floyd K. Richtmyer. Optical properties of thin films. (Additional to 196.)	500
	209.	Arthur L. Foley. Photography of phases of electric discharge	150
	210.	Orin Tugman. Conductivity of thin metallic films when exposed to ultraviolet light	100
	211.	Roswell C. Gibbs. Absorption of organic and silver solutions for ultraviolet and infrared rays. (Additional to 203.)	250
	212.	Louis T. E. Thompson. Development of a gunsight for antiaircraft guns	250
1919.	213.	Harrison M. Randall. Infrared spectrum. (Additional to 188.)	200

1919.	214.	Alpheus W. Smith. Hall effect and allied phenomena in rare metals and their alloys. (Additional to 172.)	$100
	215.	In aid of publication of Marie's Annual International Tables of Constants, through Julius Stieglitz. (Additional to 207.)	250
	216.	Arthur G. Webster. Researches on pyrodynamics and practical interior ballistics	500
	217.	Percy W. Bridgman. Effect of temperature and pressure on physical properties of materials, particularly thermal conductivity. (Additional to 185.)	400
	218.	Horace L. Howes. Effect of temperature on luminescence and selective radiation of rare earths	500
	219.	Frances G. Wick. Phosphorescence of hexagonite and fluorite, at ordinary and low temperatures	300
	220.	Robert W. Wood. Optical researches. (Additional to 158.)	350
	221.	Frederick G. Keyes. Heats of neutralization at different temperatures. (Additional to 166.)	300
1920.	222.	Frederick A. Saunders. Spectral lines. (Additional to 177.)	150
	223.	David L. Webster. X-ray spectra. (Additional to 199.)	350
	224.	In aid of publication of Marie's Annual International Tables of Constants, through Julius Stieglitz. (Additional to 215.)	250
	225.	Leonard R. Ingersoll. Polarizing effect of diffraction gratings	150
	226.	Harrison M. Randall. Structure of spectra, in infrared. (Additional to 213.)	500
	227.	Arthur G. Webster. Pyrodynamics and interior ballistics. (Additional to 216.)	500
	228.	Norton A. Kent. Spectral lines. (Additional to 197.)	200
	229.	William W. Campbell. For the purchase of a special photographic lens. (Additional to 139.)	360
	230.	Horace L. Howes. Researches in luminescence. (Additional to 218.)	90

1920.	231.	Percy W. Bridgman. Thermal and optical properties of bodies under high pressures. (Additional to 217.)	$400
1921.	232.	Paul F. Gaehr, Wells College. Specific heat of tungsten	250
	233.	Alpheus W. Smith, Ohio State Univ. Hall, Nernst and allied effects	200
	234.	Leonard R. Ingersoll, Univ. of Wisconsin. Magnetic-rotation dispersion, particularly of invisible radiations	200
	235.	Norton A. Kent, Boston Univ. Purchase of a Lummer plate. (Additional to 228.)	500
	236.	Harvey N. Davis, Harvard Univ. Improvement of the design of liquid-air machinery	300
1922.	237.	Percy W. Bridgman, Harvard Univ. Thermal and optical properties of matter under high pressures	500
	238.	Frederick A. Saunders, Harvard Univ. Spectroscopic researches	150
	239.	William Duane, Harvard Univ. Heat energy of electrons	300
	240.	W.W.Campbell, Lick Observatory, Mt. Hamilton, California. Installing a coarse grating to cover the upper end of the Crossley reflecting telescope at the Lick Observatory	475
	241.	A. G. Webster, Clark Univ. Thermodynamic problems of interior ballistics	500
	242.	Norton A. Kent, Boston Univ. Constitution of spectral lines	150
	243.	John R. Roebuck, Univ. of Wisconsin. Procuring of porous plugs for the Joule-Kelvin experiment	125
1923.	244.	William Duane, Harvard Univ. Heat energy of electrons. (Additional to 239.)	200
	245.	Harlow Shapley, Harvard Univ. Purchase of a thermoelectric microphotometer	500
	246.	R. W. Wood, Johns Hopkins Univ. Purchase of a Lummer plate for the study of magneto-optic polarization phenomena	250
1924.	247.	R. W. Wood, Johns Hopkins Univ. Continuation of previous grant	200
	248.	Norton A. Kent, Boston Univ. Constitution of spectral lines. (Additional to 242.)	250

1924.	249.	Percy W. Bridgman, Harvard Univ. Thermodynamic properties of matter. (Additional to 237.)	$500
1925.	250.	S. A. Mitchell, McCormick Observatory, Univ. of Virginia. Towards printing of observations on variable stars	500
	251.	S. Stillman Berry, Redlands, California. Light production in cephalopods	300
	252.	F. A. Saunders, Harvard Univ. Towards equipment for mapping spectra	200
	253.	G. Shannon Forbes, Harvard Univ. Photokinetics	250
	253A.	National Research Council, annual payment in aid of publication of its Table of Constants	200
	254.	George R. Harrison, Stanford Univ. Research on photographic photometry	350
	255.	Harlan T. Stetson, Harvard Univ. Instrument in the measurement of coronal radiation	120
	256.	John R. Roebuck, Univ. of Wisconsin. Apparatus for the measurement of the mechanical equivalent of heat	275
1926.	257.	Harlow Shapley, Harvard College Observatory. Construction of a thermoelectric microphotometer for stellar work	500
	258.	George W. Pierce, Harvard Univ. Photoelectric research	200
1927.	259.	J. C. Hubbard, New York Univ. Ratio of specific heats of liquids from measurements of the velocity of sound	200
	260.	International Table of Constants; usual annual appropriation	200
	261.	P. W. Bridgman, Harvard Univ. Thermal properties of matter, especially under high pressure. (Continuation.)	500
	262.	Sebastian Albrecht, Dudley Observatory, Albany, N. Y. Purchase of a spectrophotometer in the measurement of stellar wave lengths	500
	263.	Paul Kirkpatrick, Univ. of Hawaii. Apparatus in researches on X-ray reflection	250
	264.	Harlow Shapley, Harvard College Observatory. Construction of a stellar comparator for use in researches on the proper motion and variability of stars	500

1927.	265.	Norton A. Kent, Boston Univ. Apparatus to be used in researches on spectrum analysis	$150
	266.	John R. Roebuck, Univ. of Wisconsin. Apparatus to be used in the measurement of the mechanical equivalent of heat. (Additional to 256.)	500
1928.	267.	Annual contribution to the International Table of Constants	200
	268.	Raymond T. Birge, Univ. of California. Spectrum analysis	200
	269.	G. W. Pierce, Harvard Univ. Apparatus to be used in measurements on the velocity of light	300
	270.	W. J. Luyten, Harvard College Observatory. Photographic supplies in research on stellar luminosities	300
	271.	P. W. Bridgman, Harvard Univ. Investigations of thermal and optical properties of matter especially at high pressures	500
	272.	Arthur H. Compton, Univ. of Chicago. Optical equipment in photographing tracks of beta rays excited by X rays	500
	273.	George W. Pierce, Harvard Univ. Equipment for research on light waves and electromagnetic waves	500
1929.	274.	H. T. Stetson, Harvard Univ. Apparatus in investigating effects of variation in solar radiation on ionization of the earth's upper atmosphere	300
	275.	E. L. Chaffee, Harvard Univ. Electrical responses of the retina to light	100
	276.	George R. Harrison, Stanford Univ. Spectrophotometry	300
	277.	Annie J. Cannon, Harvard College Observatory. Objective prism for stellar spectrophotographic research	500
	278.	Harlan T. Stetson, Ohio Wesleyan Univ. Equipment for solar radiation researches	200
1930.	279.	Norman Feather, Johns Hopkins Univ. Equipment in radio absorption	500
	280.	H. H. Plaskett, Harvard College Observatory. Equipment for astrophotometry	500
	281.	P. W. Bridgman, Harvard Univ. Equipment for researches on thermal and optical properties of matter	500

1930.	282.	D. C. Stockbarger, Mass. Institute of Technology. Equipment for infrared spectrophotometry	$500
	283.	G. H. Dieke, Johns Hopkins Univ. Equipment for spectrophotographic research	300
	284.	T. C. Poulter, Iowa Wesleyan College. Equipment for researches on effects of pressure on the behavior of light	300
	285.	E. C. Kemble and F. H. Crawford, Harvard Univ. Equipment for spectrophotographic researches	375
1931.	286.	H. Shapley and W. J. Fisher, Harvard College Observatory. Equipment for meteor research	450
	287.	J. W. McBain, Stanford Univ. Equipment for research on light-scattering power of sols, gels, and liquid soaps	475
	288.	J. C. Stearns, Univ. of Denver. Equipment for research on cosmic rays	300
	289.	A. T. Evans, Miami Univ., Oxford, Ohio. Equipment for research on influence of radiation upon certain lower plants	200
	290.	George R. Harrison, Mass. Institute of Technology. Equipment for research on intensities of spectral lines from multiply ionized atoms.	500
	291.	C. E. Mendenhall, Univ. of Wisconsin. Equipment for research on the photoelectric properties of metals	500
	292.	W. R. Frederickson, Syracuse Univ. Equipment for studying the Faraday effect spectra in diatomic molecules	300
	293.	P. W. Bridgman, Harvard Univ. Equipment for researches on thermal and optical properties of matter. (Continuation.)	500
	294.	Harlan T. Stetson, Ohio Wesleyan Univ. Equipment for measuring solar radiation	300
	295.	F. E. Ross and G. A. Van Biesbroeck, Yerkes Observatory, Williams Bay, Wisconsin. Thermoelectric pyrometer equipment	400
1932.	296.	H. M. O'Bryan, Mass. Institute of Technology. Equipment for spectroscopic researches	500
	297.	J. C. Stearns, Denver Univ. Equipment for researches on cosmic rays	300
	298.	G. W. Kenrick, Tufts College. Equipment for research on the effect of solar radiation on the Kennelly-Heaviside layer	400

1932.	299.	Willi Cohn, A. D. Little & Co., Cambridge, Mass. Equipment for research on the polarization of light from the solar corona	$250
	300.	Cecilia H. Payne, Harvard College Observatory. Equipment for research in stellar photometry and colorimetry	200
	301.	R. H. Frazier, Mass. Institute of Technology. Equipment for researches on the thermal properties of metals	100
	302.	D. C. Stockbarger, Mass. Institute of Technology. Equipment for research on the production of artificial crystals in optical apparatus	500
	303.	A. C. Hardy, Mass. Institute of Technology. Equipment for colorimetric research	500
	304.	J. R. Roebuck, Univ. of Wisconsin. Equipment for Joule-Thomson measurements	100
1933.	305.	J. C. Stearns, Denver Univ. Equipment for cosmic researches	300
	306.	G. W. Kenrick, Tufts College. Equipment for extension and continuation of his research on the effects of solar radiation on the ionized layers	500
	306A.	W. J. Crozier, Harvard Univ. Use of certain optical apparatus including Nicol prisms	
	307.	W. J. Luyten, Univ. of Minnesota. Equipment for astrophotometric research	50
	308.	Norton A. Kent, Boston Univ. Equipment for luminous wave length researches	250
	309.	C. E. Teeter, Jr., Waverley, Mass. Equipment for research on thermal properties of gases	250
	310.	Jan Schilt, Columbia Univ. Photoelectric equipment for astronomical measurements	200
	311.	Joel Stebbins, Univ. of Wisconsin. Equipment for astronomical research	300
	312.	G. R. Harrison, Mass. Institute of Technology. Equipment for spectroscopic research	400
1934.	313.	A. G. Worthing, Univ. of Pittsburgh. Equipment for research on properties of matter at high temperatures	350
	314.	P. W. Bridgman, Harvard Univ. Equipment for researches on thermal and optical properties of matter	400
	315.	J. C. Stearns, Univ. of Denver. Equipment for cosmic-ray research	300

1934.	316.	C. E. Bennett, Mass. Institute of Technology. Equipment for research on refractive index of gases under varied impressed conditions	$400
	317.	D. C. Stockbarger, Mass. Institute of Technology. Equipment for research on growth of optical crystals	400
	318.	C. E. Teeter, Jr., Waverley, Mass. Equipment for research on the Joule-Thomson effect	100
	319.	Bart J. Bok, Harvard Univ. Equipment for research on radial velocities in the spectra of faint stars	400
1935.	320.	J. R. Roebuck, Univ. of Wisconsin. Equipment for research on thermal properties of gases	149.36
	321.	J. A. Bearden, Johns Hopkins Univ. Equipment for research on X rays	400
	322.	Simon Freed, Univ. of Chicago. Apparatus for the liquefaction of hydrogen	350
	323.	G. W. Kenrick, Tufts College. Apparatus for investigations of the Kennelly-Heaviside layer	250
	324.	Otto Struve, Yerkes Observatory, Williams Bay, Wisconsin. Apparatus for the photometric study of the night sky	300
	325.	C. F. Brooks, Blue Hill Observatory. A 12-junction pyrheliometer	100
	326.	George R. Harrison, Mass. Institute of Technology. Salts of the rare earths for spectroscopic analysis	300
	327.	T. E. Sterne, Harvard College Observatory. Galvanometer for astroradiometric studies	400
	328.	Joseph C. Boyce, Mass. Institute of Technology. An ultraviolet lens for spectroscopic studies of the coming eclipse	200
	329.	Harald H. Neilsen, Ohio State Univ. Special echelette grating for infrared spectroscopy	350
1936.	330.	Paul C. Cross, Stanford Univ. A 21-foot grating to be used in studies of molecular spectra	300
	331.	George R. Harrison, Mass. Institute of Technology. Highly purified chemical elements for spectroscopic purposes	400
	332.	Percy W. Bridgman, Harvard Univ. Investigations of thermal and optical properties of substances at very high pressures	400

1936.	333.	Newell S. Gingrich, Univ. of Missouri. A Phillips Metalix copper target X-ray tube, for researches on X-ray diffraction patterns of liquids . .	$395
	334.	Charles E. Teeter, Jr., Cambridge School of Liberal Arts. Apparatus for his investigations on the heat capacity at constant pressures and Joule-Thomson coefficient for various gases .	300
	335.	Donald C. Stockbarger, Mass. Institute of Technology. Calcium fluoride crystallization . .	400
1937.	336.	G. H. Dieke, Johns Hopkins Univ. Spectroscopic equipment	300
	337.	Norton A. Kent, Boston Univ. Spectroscopic researches	300
	338.	George R. Harrison, Mass. Institute of Technology. Spectroscopic researches, and particularly for the purchase of salts of rare earths	400
1938.	339.	Francis Bitter, Mass. Institute of Technology. Construction of a crystal for his magnetic researches	400
	340.	Richard Tousey, Tufts College. Reflections in the ultraviolet	100
	341.	E. A. Fath, Carleton College. Research on a Cepheid variable	175
	342.	Clarence M. Zener, College of City of New York. Oscillator for experiments on the connection of internal friction in solids and thermal conductivity	385
	343.	T. E. Sterne, R. M. Emberson, R. Loevinger. Construction of automatic recording apparatus for the radiometer attached to the Wyeth reflector at Oak Ridge, Harvard, Mass. . . .	290
1939.	344.	Frances G. Wick, Vassar College. Spectrometer for the study of luminescence	400
	345.	Francis Birch, Harvard Univ. Effect of stress upon the thermal conductivity of rocks and other materials of geological interest . . .	400
	346.	G. Z. Dimitroff and H. W. French, Harvard Univ. Development of the electron multiplier and amplifier for measurement of faint sources of light	250
	347.	W. M. Powell, Kenyon College. Special studies in radiation	175

1939.	348.	R. W. Wood, Johns Hopkins Univ. Construction of various prisms and optical flats	$300
	349.	Newell S. Gingrich, Univ. of Missouri. X-ray spectrometer for use in the study of the diffraction of X rays by fluids	375
	350.	E. J. Schremp, Washington Univ. Apparatus for study of the fine structure of cosmic rays	400
	351.	H. M. O'Bryan, Georgetown Univ. Absorption of films of alkali metals in the ultraviolet and the absorption of crystals above 1100 A.	400
	352.	George R. Harrison, Mass. Institute of Technology. Pure metals in connection with his spectrum work	400
	353.	P. W. Bridgman, Harvard Univ. Measurement of various thermodynamic properties of matter at high pressure	400
1940.	354.	Wilson M. Powell, Kenyon College. Search for narrow showers, consisting of mesotrons, in cosmic-ray phenomena	165
	355.	Chauncey Starr, Mass. Institute of Technology. Magnetic properties of various compounds and alloys	400
	356.	Donald H. Menzel, Harvard College Observatory. Quantitative determination of the chemical composition of the solar atmosphere	275
	357.	Frank Schlesinger, Yale University. Installation of an electron multiplier for use in the determination of stellar magnitudes	150
	358.	Lyman G. Parratt, Cornell Univ. X-ray spectroscopic studies of the solid state	325
	359.	E. J. Schremp, Washington Univ. Experimental research in cosmic rays	400
	360.	Wilson M. Powell, Kenyon College. Cosmic-ray researches on Mount Evans	250
	361.	John W. Evans, Mills College, Oakland, California. Researches on the solar surface	310
1941.	362.	Charles F. Brooks, Blue Hill Observatory. Construction of a sensitive radiometer for the measurement of long-wave atmospheric radiation	300
	363.	A. H. Pfund. Johns Hopkins Univ. Construction of a modern infrared spectroscope	400
	364.	J. R. Roebuck, Univ. of Wisconsin. Joule-Thomson effect.	200

1941.	365.	E. P. Little, Phillips Exeter Academy. Measurement of the optical properties of various metals in the Schumann region	$280
	366.	C. T. Elvey, McDonald Observatory, Austin, Texas. Construction and use of apparatus for studying the light of the night sky	400
	367.	K. W. Meissner. Construction of atomic-beam apparatus	250
	368.	E. J. Schremp, Univ. of Cincinnati. Cosmic-ray researches	400
	369.	G. Z. Dimitroff, Harvard Univ. Sensitivity of photographic emulsions	400
	370.	Wilson M. Powell, Kenyon College. Continued support of cosmic-ray researches	250
1942.	371.	J. C. Stearns and D. K. Froman, Univ. of Denver. Study of mesotrons in cosmic-rays at both Denver and Mount Evans	400
1943.	372.	Alvin H. Nielsen, Univ. of Tennessee. A rock-salt prism and four pairs of rock-salt windows for study of the vibration-rotation bands of certain polyatomic molecules	350
1944.	373.	Richard H. Goodwin, Univ. of Rochester. Kleet Fluorimeter-Colorimeter and certain accessories for studies on the effect of light upon the development of pigments in plants	300
1945.	374.	William J. Luyten, Univ. of Minnesota. To determine color indices and to discover new white dwarfs among 15,000 faint stars of appreciable proper motion in the south polar region of the sky	250
1946.	375.	Leo L. Beranek, Harvard Univ. Transfer of acoustic energy into heat energy in samples of fibrous materials	400
	376.	O. Oldenberg, Harvard Univ. Kinetics of free hydroxyl radicals	400
1947.	377.	William J. Luyten, Univ. of Minnesota. Motions and luminosities of dwarf binary stars	250
	378.	Stefan L. Piotrowski, Cracow, Poland. Construction of a photoelectric photometer for work on eclipsing binaries in co-operation with the International Astronomical Union's panel on eclipsing binaries	500

1948.	379.	William F. Meggers, National Bureau of Standards, Washington, D. C. Spectroscopic researches at the Bureau of Standards by Professor M. A. Catalan of Madrid, Spain . . .	$550
	380.	Francis Birch, Harvard Univ. Preparing conductivity specimens from rocks from the Alva B. Adams Tunnel	400
	381.	Otto Glaser, Amherst College. Spectroscopic measures for research on mineral metabolism in fundulus eggs and copper traffic in ascidian larvae	250
	382.	R. F. Daubenmire, State College of Washington. Two hygrothermographs for an ecological study of forest types in the northern Rocky Mountains	500
1949.	383.	Harold Scheraga, Cornell Univ. Special optical equipment for the study of double refraction produced in solutions of macromolecules by external electric fields	800
	384.	Donald C. Stockbarger, Mass. Institute of Technology. A polarizing microscope for researches on optical crystals	750
	385.	Cecilia Payne-Gaposchkin, Harvard College Observatory. Towards a total of $1500 for construction of a photoelectric photometer and adaptation of a 24-inch reflector for researches in stellar variation and stellar evolution . .	750
	386.	Stanley S. Ballard, Tufts College. Design and construction of apparatus for measuring the thermal conductivity of small samples of poorly conducting materials such as optical crystals .	600
	387.	William J. Luyten, Univ. of Minnesota. Photographic supplies for a joint research of the University of Minnesota and the Argentinian observatory at Córdoba	250
	388.	C. M. Huffer, Washburn Observatory, Madison, Wisconsin. Analysis of photoelectric light curves of eclipsing binaries at the Center of Analysis of the Mass. Institute of Technology .	400

Proceedings of the American Academy of Arts and Sciences

Vol. 78, No. 3, P. 135–184—April, 1950

SOME INTERSPECIFIC RELATIONSHIPS IN PHACELIA SUBGENUS COSMANTHUS

By Lincoln Constance

ON THE THEORY OF ACOUSTIC RADIATION PRESSURE

By J. S. Mendousse

THERMODYNAMIC RELATIONS IN n-VARIABLE SYSTEMS IN JACOBIAN FORM:

PART I, GENERAL THEORY AND APPLICATION TO UNRESTRICTED SYSTEMS

By F. H. Crawford

SOME INTERSPECIFIC RELATIONSHIPS IN PHACELIA SUBGENUS COSMANTHUS*

By Lincoln Constance

(*Department of Botany, University of California, Berkeley*)

Received April 1, 1949

CONTENTS

Introduction

The study of "Evolution" has in recent years been so monopolized by experimental geneticists with their interest in induced mutations, by cytogeneticists concerned with polyploidy, and by paleontologists with their concrete historical evidence, that it may sometimes be overlooked that taxonomists have been concerned with phylogenetic considerations for at least a century and probably much longer. The successive supplanting of Artificial by Natural classifications, and of Natural by avowedly Phylogenetic schemes, bears witness to this fact. In general, however, the taxonomist treats with such broad groups that his attention to any particular population must necessarily be somewhat perfunctory. To many systematists the classical revisionary treatment, with keys, descriptions, and ordered nomenclature, is the ultimate goal of the study. Having fastidiously and laboriously completed such a document, they may pass unconcernedly on to another, frequently quite unrelated problem. Perhaps the taxonomist's reluctance to suggest or accept premature and too facilely constructed genealogies has sometimes led to his dismissal as a mere shuffler of specimens and nomenclature, with nothing of value to offer to evolutionary theory.

Although he usually has no evidence from the fossil record and only exceptionally has the opportunity to grow and manipulate the plants with which he is concerned, the taxonomist may still be able to contribute something to the evolutionary picture by combining his observations on comparative morphology with those gained from field study, as it is hoped this paper may indicate. Because he is

* Introduced by I. M. Johnston and R. C. Rollins.

usually concerned with naturally occurring species, he must often pioneer, for only recently has the geneticist begun to emerge from his laboratory or to shift his attention to other than economically important plants. That wild plants of no apparent immediate value may reveal additional genetic and evolutionary information, however, is quite as likely as that such significant data are discoverable only in our cultigens. The taxonomist can render a useful service in pointing out and underlining problems suitable for manipulatory and statistical attack and he is, at the same time, in a favorable position to test and apply hypotheses and generalizations reached on the basis of controlled experimentation. It should perhaps be emphasized that when the problems he poses are subsequently explored experimentally or mathematically and the results applied to classification of the organisms involved, these activities are as truly taxonomic as his original, more exploratory and descriptive studies. Changes in approach and instrumentation do not alter the general objectives of the field. Taxonomy is a sufficiently broad discipline to incorporate contributory data from all lines of research, so long as these are properly documented and have a bearing upon relationship.

THE GENERAL PROBLEM IN *Cosmanthus*

The present paper is an attempt to distill from a revisionary study (Constance, 1949) of *Phacelia* subgenus *Cosmanthus*, of the family Hydrophyllaceae, some indications as to the evolutionary history of three selected entities. An intensive investigation of the group based upon comparative morphology, including chromosome number, was supplemented by a month's field work in critical areas, assisted by a grant from the Permanent Science Fund of the American Academy of Arts and Sciences and the sponsorship of Southern Methodist University and the Texas Research Foundation. A careful examination of dried specimens had made it quite apparent that the interrelationships of some of the species were too complex to be ascertained by herbarium studies alone. The writer hoped that differential chromosome numbers and possibly allopolyploidy might furnish some tenable explanations. This hope was not realized because the particular entities involved, insofar as cytological material could be obtained, all proved to be homoploid and to have nine pairs of chromosomes (Cave and Constance, 1947, 1950).

Nevertheless, the correlation or coincidence of distributions and morphological features appears to show a pattern or patterns which may prove to be of some general interest. As has been suggested above, the revisionary study of this group has posed problems which would appear to be suitable for genetic attack, and the study has

concluded by showing the eminent desirability of other investigations which the writer is, unfortunately, not in a position to undertake. It should be firmly borne in mind that the suggestions as to affinity made here have no genetic documentation whatsoever and are thus necessarily highly circumstantial and conjectural. They may, nevertheless, afford some clues to the existence of an evolutionary pattern to be sought for in other groups occurring under similar habitat conditions in the same or completely different areas.

Three Specific Cases in Cosmanthus

Of the three cases selected for presentation here, each involves a trio of species or varieties; one member of each trio appears to be derived from the other two members of the same trio. These do not correspond to the usual situations of two entities of overlapping distribution possessing a thin band of sporadic hybrid progeny in the zone of overlap, nor to the introgression of characters of one species or variety into another one as discussed by Anderson in his recent provocative essay (1949) on this subject, although introgression may well be involved. Instead, the morphologically intermediate populations give every appearance of being as vigorous as their presumed parental species, show no cytological irregularities and have distributions which indicate that they are successfully established and even aggressive in areas and habitats occupied by only one or neither of the two parental types. If the relationships suggested here are substantiated by further studies, they may point the way to modes of origin not generally accounted for in the literature of the genetics of wild plants.

No attempt is made to present the relevant data in quantitative terms nor to stress their significance by graphic statistical or ideographic devices. Statistical techniques, justly or unjustly, often carry connotations of objectivity and finality which would be singularly inappropriate as applied to the purely qualitative data and very tentative hypotheses of affinity suggested here. There is no doubt in my mind, however, that the employment of hybrid indices of one sort or another to the material studied would point in the same direction as does the empirical evidence. Instead, it is hoped that a tabular presentation of differences and resemblances, accompanied by illustrations of the plants concerned and maps of their distribution, will suffice to make the problems clear.

(*1*) *Phacelia strictiflora* var. *Robbinsii*.—Disregarding two of the infraspecific populations comprising the notably polytypic *Phacelia strictiflora* (Engelm. & Gray) A. Gray, we may focus our attention upon two others, var. *Robbinsii* Const. and var. *Lundelliana* Const., and

their relationship to a second species, *P. hirsuta* Nutt. The characters by which var. *Robbinsii* differs rather strikingly from var. *Lundelliana* are almost exactly those in which it agrees with *P. hirsuta* (Table 1 and Figure 1).

TABLE 1

Phacelia strictiflora var. *Lundelliana* ($n = 9$)	*Phacelia strictiflora* var. *Robbinsii* ($n = 9$)	*Phacelia hirsuta* ($n = 9$)
Stems and branches stout.	Stems and branches slender.	Stems and branches slender.
Basal leaves persistent, succulent, glabrate beneath, entire to shallowly toothed.	Basal leaves sub-persistent, membranaceous, strigose beneath, deeply lobed to pinnatifid.	Basal leaves early-withering, membranaceous, strigose beneath pinnatifid or pinnate.
Cauline leaves shallowly toothed.	Cauline leaves deeply lobed to pinnatifid.	Cauline leaves deeply lobed to pinnatifid.
Pedicels strictly erect or stiffly ascending, 2-10 mm. long.	Pedicels stiffly to rather loosely ascending, 2-10 mm. long.	Pedicels loosely ascending to widely spreading, 3-15 mm. long.
Calyx lobes, especially the lowermost, markedly accrescent.	Calyx lobes little or not at all accrescent.	Calyx lobes scarcely accrescent.
Ovules 8-14 to each placenta.	Ovules 8-14 to each placenta.	Ovules usually 4 to each placenta.

In the diagnostically significant features of possession of a basal rosette, short pedicels, and a larger number of ovules, it is clear that vars. *Lundelliana* and *Robbinsii* are members of the same species and distinct from *P. hirsuta*.

As shown by the map (Figure 2), var. *Robbinsii* occurs partly near but not within the area where the ranges of *Phacelia strictiflora* and *P. hirsuta* overlap. The habitat of var. *Lundelliana* appears always to be in sandy soil, often in or near oak woods; *P. hirsuta* has been collected chiefly in oak woods, but usually in loamy alluvial, calcareous or cherty soil. The habitat of var. *Robbinsii* is usually noted as the loam of open meadows, forest openings, or rocky hillsides; the type locality contains weathered material from nearby granite knobs. The habitat of var. *Robbinsii* thus approaches in some respects that of *P. hirsuta*. The areas comprising these habitats have been so greatly altered by clearing, grazing, and agriculture that it is not clear what the original ecological preferences of these entities may have been.

P. strictiflora Lundelliana P. strictiflora Robbinsii P. hirsuta

FIGURE 1. Habit sketch of *Phacelia strictiflora* vars. *Lundelliana* and *Robbinsii* and *P. hirsuta*. × ½.

Inasmuch as var. *Robbinsii* appears to be fertile and self-perpetuating, and has extended its range beyond that of both the forms which circumstantial evidence suggests may have been its parents, it may be supposed that there was some available intermediate habitat (original or man-made) in which the hybrid derivatives were more successful than were the original forms themselves.

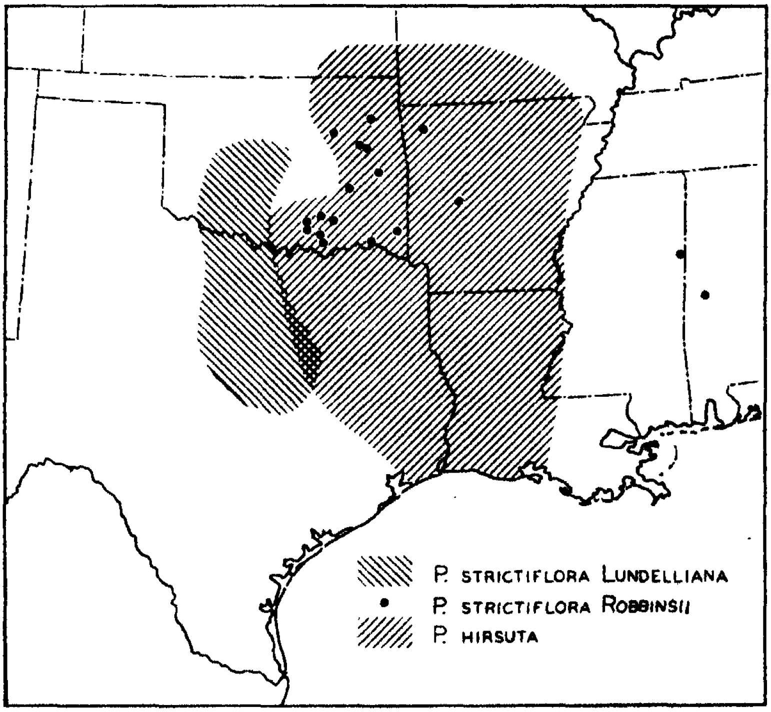


FIGURE 2. Distribution of *Phacelia strictiflora* vars. *Lundelliana* and *Robbinsii* and *P. hirsuta*.

(2) *Phacelia patuliflora* var. *patuliflora*.—The second case involves *Phacelia patuliflora* (Engelm. & Gray) A. Gray and *P. laxa* Small. The former species has two phases, var. *teucriifolia* (Johnst.) Const., chiefly of the Edwards Plateau of Texas but extending southward into Coahuila, and var. *patuliflora* of central and southeastern Texas and adjacent Mexico. Morphologically, var. *patuliflora* is extremely variable, and appears to consist of numerous interlocking geographical races and local forms, whereas var. *teucriifolia* and *P. laxa* are both relatively uniform. Moreover, if the broad gamut of variations and

combinations exhibited by var. *patuliflora* could be arranged in a linear series, *P. laxa* would stand at one end of the series and var. *teucriifolia* at the other (Table 2 and Figure 3).

TABLE 2

Phacelia patuliflora var. *teucriifolia* ($n = 9$)	*Phacelia patuliflora* var. *patuliflora* ($n = 9$)	*Phacelia laxa* ($n = 9$)
Branches rather stiffly ascending.	Branches usually more or less decumbent.	Branches diffuse, prostrate to ascending.
Pubescence of stems finely and densely strigulose.	Pubescence of stems finely strigulose to densely spreading-hirsute.	Pubescence of stems sparsely spreading-hirsute.
Pedicels ascending.	Pedicels ascending to widely spreading or reflexed.	Pedicels widely spreading or reflexed.
Calyx lobes mostly lanceolate, acute, ascending in fruit.	Calyx lobes narrowly oblong or lanceolate to obovate, obtuse or acute, spreading to ascending in fruit.	Calyx lobes oblanceolate to obovate, obtuse, rotate-spreading to reflexed in fruit.
Corolla large, rotate-campanulate.	Corolla variable in size, rotate-campanulate to broadly campanulate.	Corolla small, broadly campanulate.

Some of the populations of var. *patuliflora*, particularly in the Rio Grande Plains, so nearly simulate var. *teucriifolia* (perhaps as a consequence of introgression) that it seems unwise to attempt to separate them specifically. On the other hand, it is usually possible to achieve a satisfactory separation from the wholly sympatric *P. laxa*, at least in the field.

In this instance the ranges of the two presumed parents do not intersect, at least at present, but they are broadly connected by that of var. *patuliflora*, which is postulated to comprise the sum of their existing hybrid derivatives. The usual habitat of var. *teucriifolia* appears to be alluvial soil along streams and in draws in West Texas; *P. laxa* is characteristically found in moist alluvial thickets along the lower courses of rivers in the Nueces Bay region (Figure 4). The var. *patuliflora* is most common in sandy soil, especially on river terraces and coastal dunes, but it occurs over a wide variety of habi-

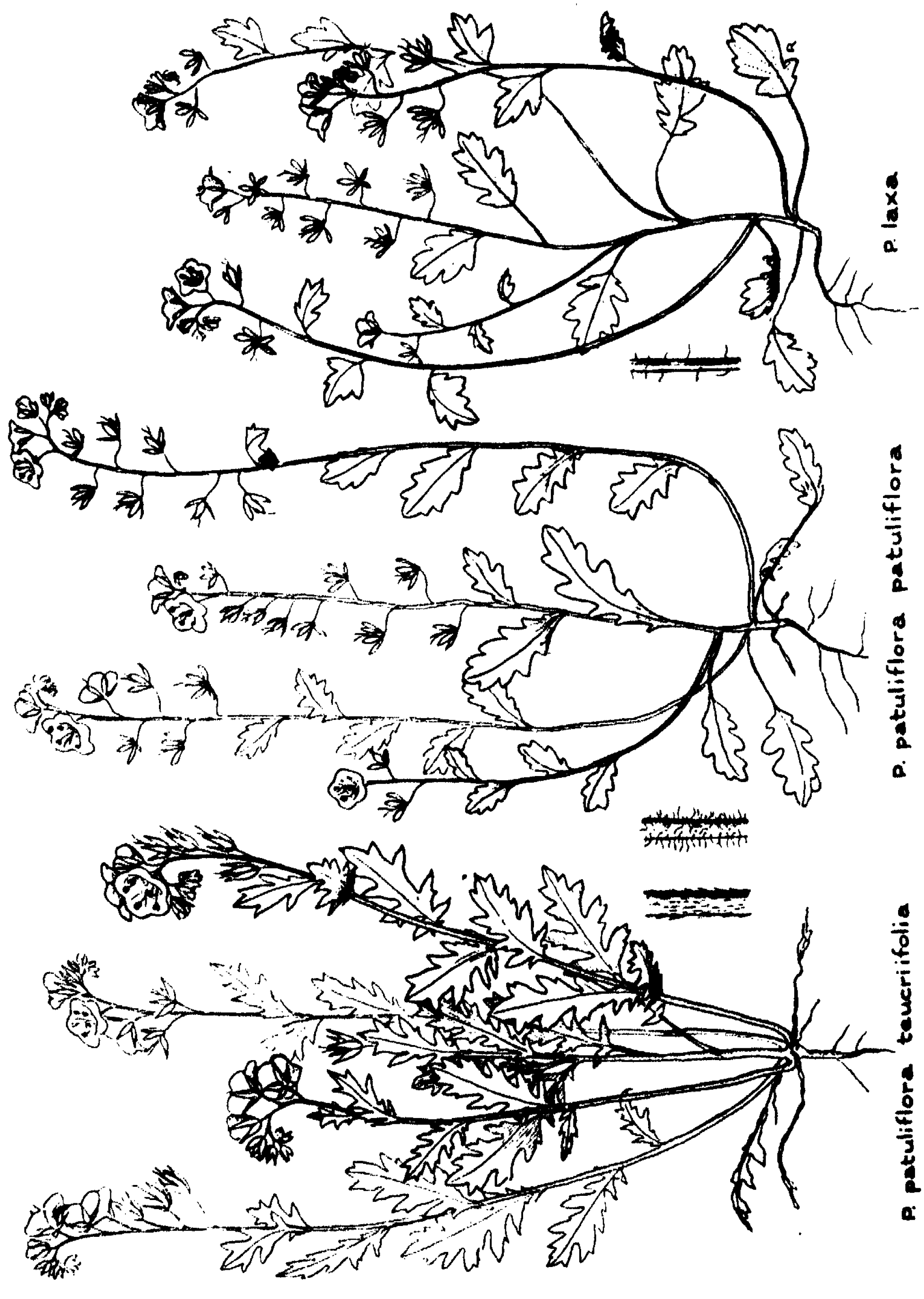


FIGURE 3. Habit sketch of *Phacelia patuliflora* vars. *teucriifolia* and *patuliflora* and *P. laxa.* × ½. Detail of stems. × ½.

tats, including roadsides and railway embankments, as well as alluvial thickets and open, sandy woods. It seems especially probable in this case that man's destruction of old habitats and creation of new environments has permitted establishment and spread of a new entity.

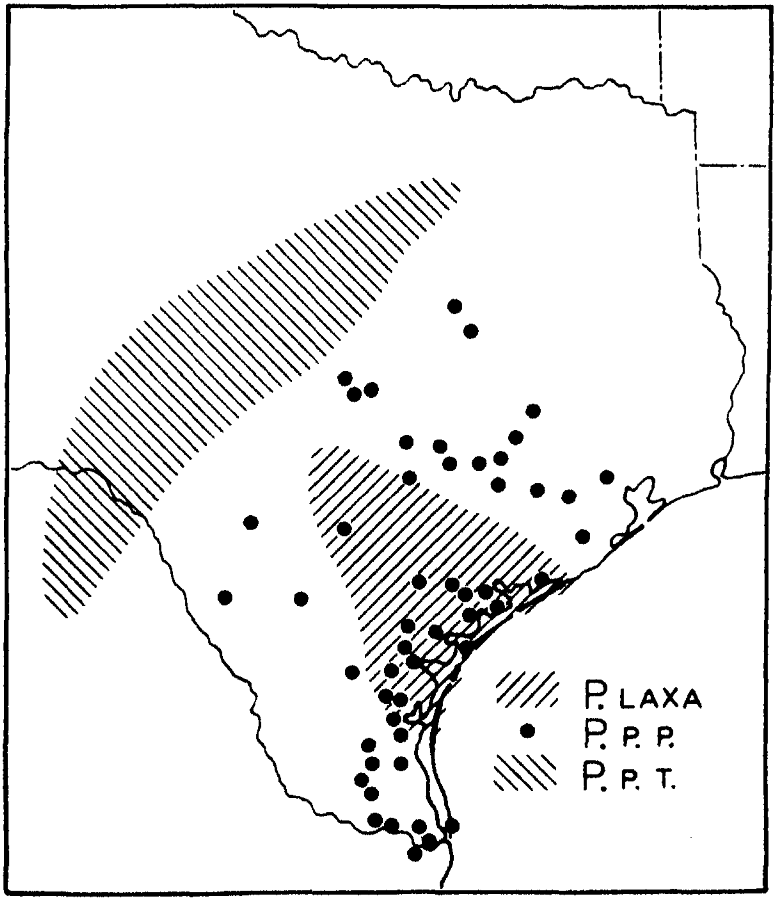


FIGURE 4. Distribution of *Phacelia patuliflora* vars. *teucriifolia* and *patuliflora* and *P. laxa*.

(3) *Phacelia gilioides*.—The third selection involves *Phacelia gilioides* Brand and its affinities with *P. Purshii* Michx. and *P. hirsuta* Nutt. The species of the genus occurring in Missouri have been confused because attempts were made to treat these three entities as only two.

Very different ideas of the distributional patterns of *P. Purshii* and *P. hirsuta* were thus obtained, depending upon which morphological criteria were employed for separation. The recognition of a third species in the area greatly assists in clarifying the picture. This entity, *P. gilioides*, is suggested to have arisen as a consequence of hybridization between the other two, but it appears now to be a fully fertile, self-perpetuating, and morphologically stable species, which has colonized some areas uninhabited by either of its hypothetical parents. The morphological evidence for this suggestion as to relationship is summarized in Table 3 and Figure 5 and the geographical in Figure 6.

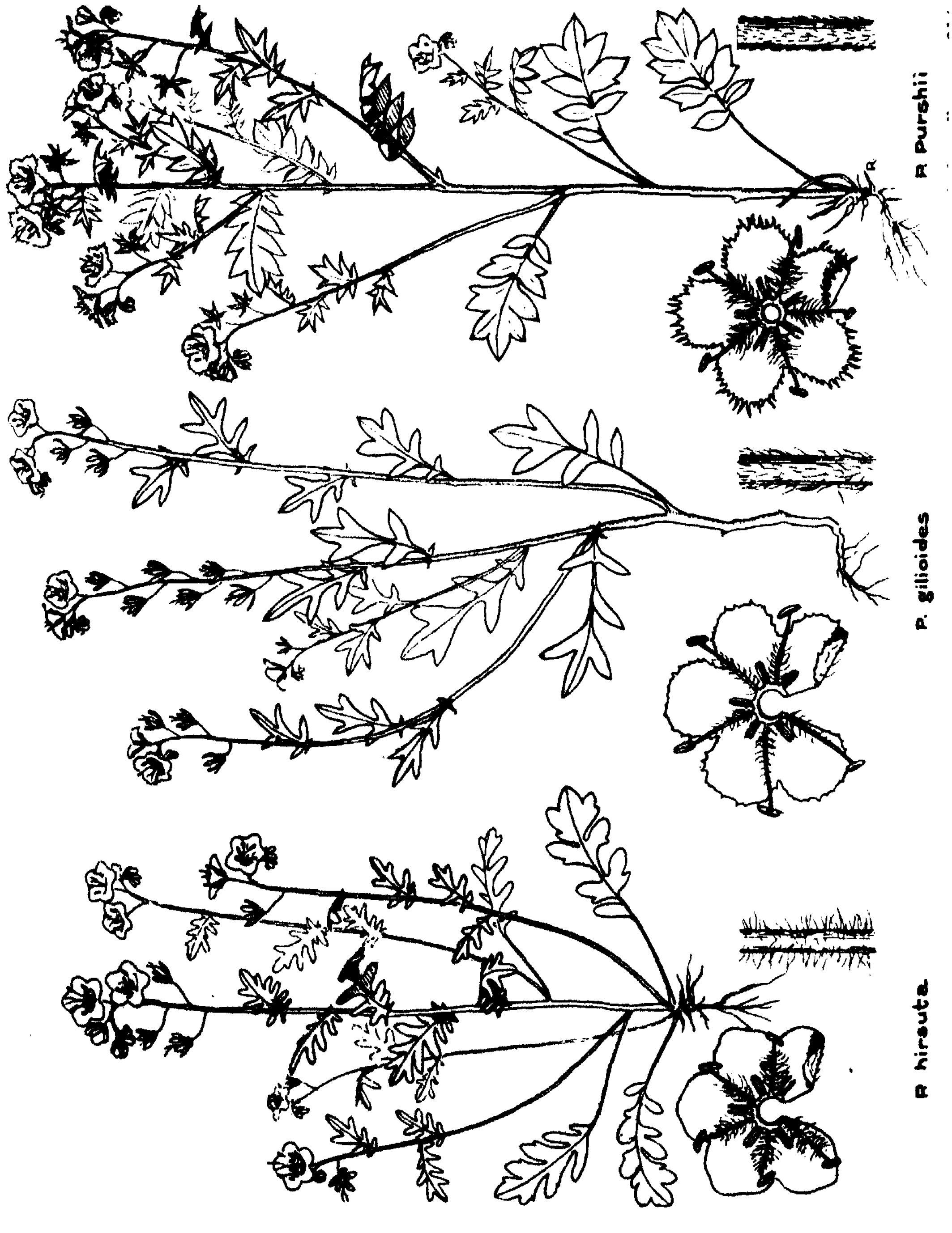
TABLE 3

Phacelia hirsuta ($n = 9$)	*Phacelia gilioides* ($n = 9$)	*Phacelia Purshii* ($n = 9$)
Pubescence of stems and inflorescence spreading-hirsute.	Pubescence of stems and inflorescence strigose, the latter canescent.	Pubescence of stems and inflorescence strigose or strigulose, often sparse.
Lobes of the cauline leaves mostly obtuse.	Lobes of the cauline leaves usually acute.	Lobes of the cauline leaves acute.
Corolla lobes entire, pilose on the back.	Corolla lobes denticulate to fimbriate, pilose on the back.	Corolla lobes deeply fimbriate, usually glabrous.
Ovules usually 4 to each placenta.	Ovules usually 4 to each placenta.	Ovules only 2 to each placenta.

The writer has no first-hand knowledge of ecological conditions where these three species occur in Missouri, and herbarium labels are not especially revealing. *Phacelia Purshii* is apparently confined largely to alluvial bottomlands; *P. hirsuta* appears to be abundant in woodlands, especially in cherty soil. The ecological niche most commonly assigned to specimens of *P. gilioides* is limestone glades or "barrens," but whether these sites differ appreciably from those supporting the partially sympatric *P. hirsuta* is not clear, and the two have been mixed, although rarely, in the same collection. Again, the ranges of the supposed parents are not known to overlap, but that of the assumed hybrid derivative connects them. Field study might reasonably be expected to provide some clue as to the environmental reasons for the persistence and successful spread of *P. gilioides*.

Discussion and Conclusion

The linear arrangement of species adopted by the writer in his recently published revision of the subgenus *Cosmanthus* had no special


P. Purshii
P. gilioides
P. hirsuta

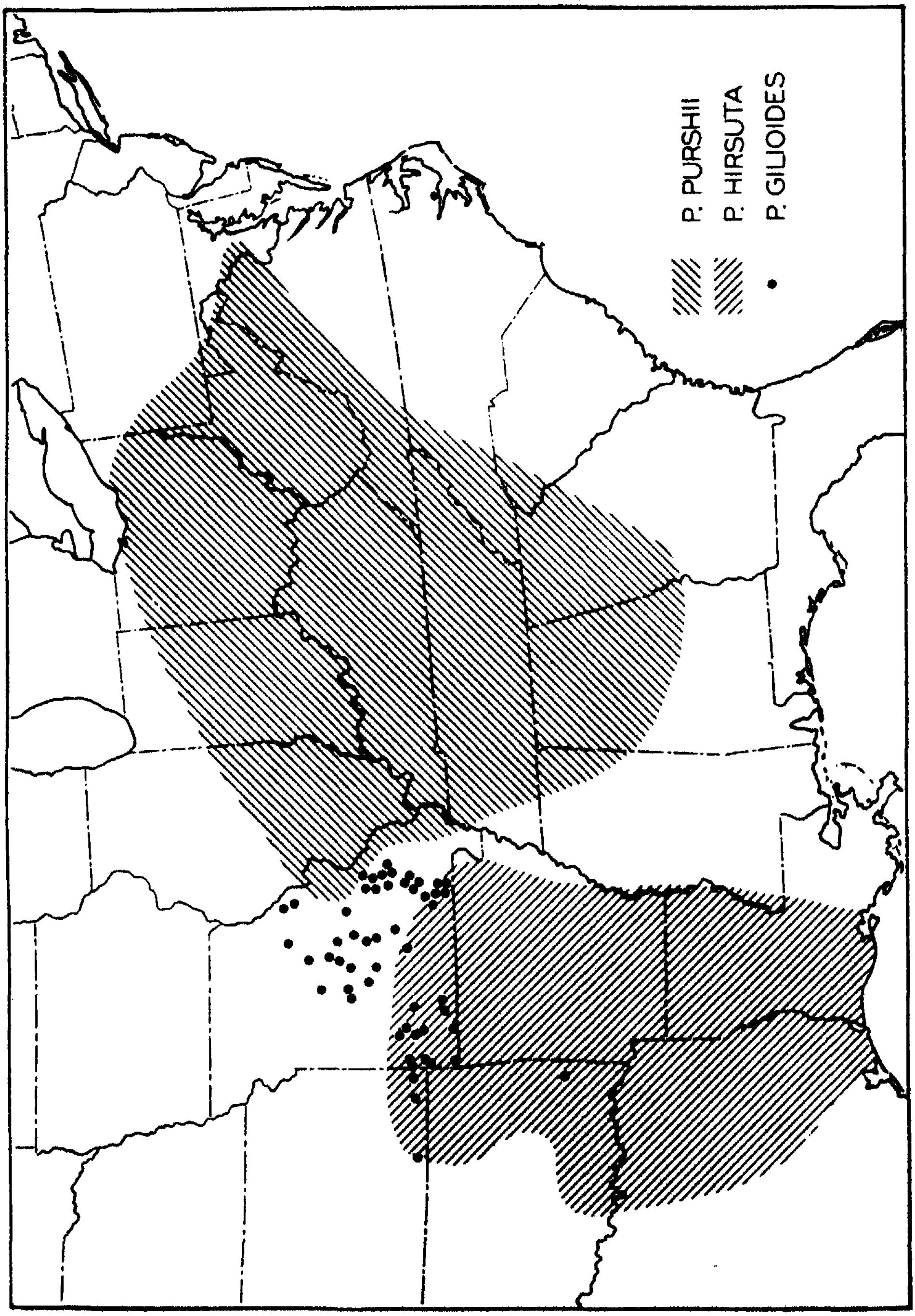


FIGURE 6. Distribution of *Phacelia hirsuta*, *P. gilioides*, and *P. Purshii*.

significance. However, it was an attempt to approximate an assumed phyletic progression, giving particular weight to reduction in number of ovules—which appears to be a general trend in the genus—and to suspected migrational history. If this arrangement has any merit, it tends to show that the species may be grouped into about four levels of advancement. Of those with which we are presently concerned, *P. strictiflora* and *P. patuliflora* would occupy the second level, *P. hirsuta* and *P. laxa* the third, and *P. Purshii* the fourth. This observation is repeated here only because it indicates that the supposed cases of hybrid derivation discussed above would all necessitate the crossing of comparatively distantly related parents. It would, perhaps, be less surprising if, for example, *P. patuliflora* crossed with *P. strictiflora*, which is of about the same level of advancement and overlaps it broadly in distribution, but this does not appear to occur. The hybridization which is significant in this group, in terms of the success of the resultant offspring, appears rather to be between species which are well defined morphologically and not too closely related.

These three examples will, it is hoped, indicate that the taxonomist, working only with his ordinary tools, may be able to throw some light on the phylogeny of the groups with which he is concerned. In none of the cases cited has the proposed explanation been established, and supplementary genetic or other investigation is earnestly invited. Only by evidence from every available source, guided by the fitful illumination of successive and even contradictory hypotheses, can we hope to approach a truly phylogenetic classification.

Literature Cited

Anderson, Edgar
1949. Introgressive hybridization. New York.
Cave, Marion S. and Constance, Lincoln
1947. Chromosome numbers in the Hydrophyllaceae: III. Univ. Calif. Publ. Bot. 18: 449–465.
1950. Chromosome numbers in the Hydrophyllaceae: IV. Univ. Calif. Publ. Bot. 23: 363–381.
Constance, Lincoln
1949. A revision of *Phacelia* subgenus *Cosmanthus* (Hydrophyllaceae). Contr. Gray Herb. 168: 1–48.

ON THE THEORY OF ACOUSTIC RADIATION PRESSURE*

By J. S. Mendousse

Wesleyan University, Middletown, Connecticut†

Received June 1, 1949

Summary

This is an attempt toward a comprehensive and rigorous treatment of acoustic radiation pressure in the case of non-viscous motions. Unlike the optical radiation pressure, for which exact formulas can be derived, the acoustic radiation pressure is usually computed by approximation methods, the accuracy of which depends on the "amplitude" of the motion. The theory presented in this paper begins with a rigorous definition of the amplitude of a whole motion, in contrast to the amplitude of vibration at a particular point. From there on the first- and second-order terms in the series expansion of the acoustic radiation pressure, and other quantities, with respect to the amplitude are rigorously derived. The development of the theory brings out a remarkable mass-energy relation: defining the equilibrium of a volume V of the fluid by the average position of its boundaries (with respect to time), the difference $(\bar{E}_p - \bar{E}_k)$ of the potential and kinetic energies inside this volume V is equal to $\frac{1}{2} mc^2$, where c is the wave velocity and m the time-average increase of mass caused by the motion inside the volume V. Finally, a formula is obtained for the radiation pressure on the walls of a container which participates in the oscillations of the fluid. Some of the formulas involve a higher approximation than that obtainable from the wave equation $\nabla^2\varphi = \ddot{\varphi}/c^2$ (φ = velocity potential), and call for a more rigorous solution of hydrodynamic problems concerning radiation pressure. The classical expressions for the force on a completely immersed body are not affected, however, as they only depend on the differences in pressure between various points of fluid, and not on absolute values. Experiments to measure these absolute values are suggested.

Definitions

1. The acoustic radiation pressure $\overline{\Delta p_i}$ at a particular point P_i

† This work was completed under contract N6onr-262 between the Office of Naval Research and Wesleyan University. The author is now at The Catholic University of America, Washington, D. C.

* Introduced by W. G. Cady.

fixed in space will be defined as the average change in pressure $(\overline{p_{i,t} - p_{i,0}})$ from the reference pressure $p_{i,0}$ at this point:

$$\overline{\Delta p_i} = \overline{p_{i,t} - p_{i,0}} \tag{1}$$

This definition is useful only when the average is practically independent of the length of time over which it is computed, as, for instance, in the case of continuous oscillatory motions (and also steady flows). Its physical meaning can be visualized by imagining that a small area dS of the walls (assumed, for simplicity, to be rigid and stationary) containing the fluid is replaced by a piston of large inertia. Then a constant external force dF has to be applied to this piston to keep it from moving away from the wall. According to the law of conservation of momentum, this force is given by the relation:

$$dF = \overline{\Delta p_i} \times dS \tag{2}$$

which shows that the radiation pressure is equal to the force acting on the unit area of the walls.

Experimentally the acoustic radiation pressure is always measured by its action on a wall or solid surface, and therefore is often computed by using expressions that are correct on the walls, but not in the bulk of the fluid. Furthermore, when the walls are those of a completely immersed body, the total force acting on this body according to Eq. (2) will not be changed by adding a constant to any expression for the radiation pressure, which again allows more freedom in the choice of a particular formula.

2. The average increase in density $\overline{\Delta \rho_i}$ at a point P_i fixed in space is defined in the same way as the average increase in pressure, according to the relation:

$$\overline{\Delta \rho_i} = \overline{\rho_{i,t} - \rho_{i,0}} \tag{3}$$

This function is introduced here chiefly as a means of expressing mathematical relations in a more convenient way, its experimental significance being less obvious than that of the acoustic radiation pressure. In the case of a transparent fluid enclosed by walls in which two plane parallel glass windows are provided, however, photometric measurements using optical interference or absorption might make it possible to measure directly the average of the above function $\overline{\Delta \rho_i}$ over the volume of a cylinder having the two windows for bases. This would make it possible to check experimentally Eq. (33) below, which involves the average increase of mass caused by the motion in such a volume.

3. In the present treatment the displacement $\xi_m(t)$ of any particle m at time t is regarded as a function of an amplitude A, but not necessarily as proportional to A. At any given value of A, $\xi_m(t)$ is completely determined when the nature and configuration of the system are known. This particular value of A defines one member of an infinite family of motions.

The amplitude A is a parameter that may be defined in any one of a great variety of ways. It may be the amplitude of motion of a piston, or the amplitude of the excess pressure at a given point, or the amplitude of the *emf* that drives an electromechanical transducer; on the other hand, we prefer to regard it as a *generalized amplitude*, and not necessarily as any physical amplitude, as long as it can be used in a power series of the type shown in Eq. (4) below. That which concerns us here is not the mechanism by which the acoustic waves are produced, but their variation with amplitude.

The configuration of the system is assumed to be completely specified by a set of coefficients $\xi_h(m, t)$, where $h = 1, 2, 3, \ldots$ Each coefficient is a function of time for any particle m, and the aggregate, for all values of m and h, describes the entire system, including the boundary conditions. The ξ_h are therefore characteristic of the family, and are the same for all members, that is, for all values of A.

We now express the displacement $\xi_m(t)$ of any particle m as a convergent power series in A:

$$\xi_m(t) = A\xi_1(m, t) + A^2\xi_2(m, t) + \ldots + A^h\xi_h(m, t) + \ldots \quad (4)$$

in which t is the time and m the symbol of the particle, usually specified in terms of its coordinates x_m, y_m, z_m in the equilibrium state.

The method indicated above systematizes a procedure implicitly contained in all treatments of wave problems. It is common practice to include in the expression for the displacement a factor representing the physical amplitude of the motion at some point, such as the source of the waves. In our definition, each value of this physical amplitude at the source corresponds to and characterizes a different state of motion. The physicist accustomed to the first-order approximation might contend that changing the physical amplitude at the source only results in multiplying the displacements at all other points by a common factor, and that the difference is entirely trivial. To this the answer is that we are dealing here with a more accurate picture of the motion. Increasing sufficiently the physical amplitude at the source will cause a distortion represented by the terms in A^2, A^3, etc. in Eq. (4), and therefore the new state of motion will be very different from the old. Moreover, our definition does not require the

generalized amplitude A to coincide with any physical amplitude, as long as it can be used in a series expansion of the type illustrated in Eq. (4).

4. When the fundamental laws of mechanics are applied to the fluid, the resulting equations can be written as power series of the generalized amplitude A equated to zero. An exact solution would make each term of these series equal to zero. The theory of acoustic radiation pressure, however, only deals with the terms of the first and second degree with respect to the amplitude. Even so, each result has to be carefully scrutinized to make sure that no second-order term is omitted in its derivation.

5. This use of series expansions in terms of a generalized amplitude A can afford a most straightforward and powerful means of solving acoustic problems. As an illustration, let us consider the case of sound waves in tubes and horns, the solution of which is well known because of its importance in the construction of loudspeakers.[26] We start from Lagrange's law of motion:

$$\rho_0 \ddot{\xi} = -p' \quad (\text{dot} = \frac{\partial}{\partial t}, \text{ prime} = \frac{\partial}{\partial x}), \tag{5}$$

in which x is the distance from the source of the waves, and from the compressibility law:

$$p - p_0 = -\rho_0 c_0^2 [\xi' + D\xi'^2 + \ . \ . \ .] \tag{6}$$

in which D is what we may call a "distortion coefficient," since it would be zero for a fluid obeying Hooke's law. On replacing ξ by its series expansion in Eq. (4), and p by its expansion in Eq. (6), Lagrange's equation splits into the new relations:

$$\ddot{\xi}_1 = c_0^2 \xi_1'' \tag{7}$$

$$\ddot{\xi}_2 = c_0^2 [\xi_2'' - D(\xi_1^2)'] \tag{8}$$

The solution of the first equation is the undistorted, fundamental wave representing the first order approximation. Assuming this fundamental wave to be simple harmonic we replace ξ_1 by $e^{j\omega(t-x/c)}$ in the second relation, thus obtaining, for the amplitude of the double-frequency harmonic in the complete motion, a differential equation of the type

$$f(y)'' + f(y) = e^{-jy} \tag{9}$$

with $y = 2\omega x/c$. This equation is integrated by using the particular solution $f(y) = ye^{-jy}$, which yields at once the correct expression for

the double-frequency harmonic generated by the distortion of the fundamental wave:

$$A^2\dot{\xi}_2 = -\pi^2 Dx \frac{A^2}{\lambda^2} e^{2j\omega(t-x/c)} \tag{10}$$

In this equation A is the displacement amplitude of the fundamental wave, and has been used throughout as generalized amplitude for the complete motion.

6. The quantities that have previously been defined, *i. e.*, the acoustic radiation pressure $\overline{\Delta p_i}$ and the average increase in density $\overline{\Delta \rho_i}$, are governed by two fundamental relations: the first deals with the static properties of the fluid and can be derived from its law of compressibility alone; the second is kinetic in nature and is obtained when the fundamental laws of dynamics are applied to the motion. These relations will be treated in the following paragraphs.

Static Relation

7. The law of compressibility of the fluid can be expanded as a power series of $\Delta p = (p - p_0)$, in which p_0 is the pressure in the reference state:

$$\rho = \rho_0 + k_1(\Delta p) + k_2(\Delta p)^2 + \ldots \tag{11}$$

If we introduce the wave velocity,

$$c = \sqrt{\frac{dp}{d\rho}} \tag{12}$$

and the distortion coefficient D already occurring in Eq. (6), this expression of the compressibility law becomes:

$$\rho = \rho_o + \frac{1}{c^2}\Delta p - \frac{D-1}{\rho_o c^4}(\Delta p)^2 + \ldots \tag{13}$$

8. The distortion coefficient D is zero for a fluid obeying Hooke's law, *i. e.*, when the pressure is a linear function of the volume. In the case of sound waves in gases, if the compression is adiabatic, the value of the distortion coefficient D is $(\gamma + 1)/2$, in which γ is the ratio of the specific heats. This gives $D = 1.20$ in the case of air. In liquids the distortion coefficient may be much larger; $D = 5$ in the case of water. As will be shown later (Par. 15), however, the larger displacement amplitudes experimentally obtainable in the case of gases more than compensate for the smaller distortion coefficient in producing observable effects.

9. Taking averages in Eq. (13) gives the new relation:

$$\overline{\Delta p} = c^2\overline{\Delta \rho} + \frac{D-1}{\rho_0 c^2}\,\overline{(\Delta p)^2} \tag{14}$$

Observing that $\rho_0 c^2$ is the compressional modulus k of the fluid, and introducing the average potential energy per unit volume,

$$\bar{e}_p = \tfrac{1}{2}\frac{\overline{(\Delta p)^2}}{k} \tag{15}$$

we can write Eq. (14) as:

$$\overline{\Delta p} = c^2\overline{\Delta \rho} + 2\,(D-1)\,\bar{e}_p \tag{16}$$

which is the "static relation" between the acoustic radiation pressure $\overline{\Delta p}$ and the average change in density $\overline{\Delta \rho}$.

Kinetic Relation

10. The fundamental laws of dynamics, applied to a fluid, may be expressed in the form of Euler's equation. For the present purpose this equation is preferably written in vectorial form:

$$H \cdot dl - \frac{dp}{\rho} = \left(\frac{\partial v}{\partial t} + \operatorname{grad}\frac{v^2}{2} - v \times \operatorname{curl} v\right) \cdot dl \tag{17}$$

The theory of the acoustic radiation pressure supposes the external field H negligible, so that the first term on the left-hand side can be omitted. The last term on the right-hand side, $v \times \operatorname{rot} v$, is of the third degree with respect to the amplitude A, since the curl of the velocity is always a second-order quantity. This last term, therefore, is not to be considered. On the left-hand side $1/\rho$ can be expanded into a power series as in Eq. (13), which gives:

$$\frac{1}{\rho} = \frac{1}{\rho_0}\left[1 - \frac{1}{\rho_0 c^2}(p - p_0) + \ . \ . \ . \ \right] \tag{18}$$

and, since the field H has been assumed to be negligible, and therefore p_0 constant over the fluid,

$$\frac{dp}{\rho} = \frac{1}{\rho_0}\,dp - d\,\tfrac{1}{2}\frac{(p-p_0)^2}{\rho_0 c^2} + \ . \ . \ . \tag{19}$$

When the average with respect to the time is taken, Eq. (19) becomes:

$$\overline{(dp/\rho)} = \frac{1}{\rho_0}\,d\,(\overline{\Delta p} - \bar{e}_p + \ . \ . \ . \ ) \tag{20}$$

in which $\bar{e}_p$ is the potential energy defined by Eq. (15). The term dv/dt on the right-hand side of Eq. (17) has a zero average since the velocity does not increase indefinitely. Consequently, if we also introduce the average kinetic energy per unit volume

$$\bar{e}_k = \tfrac{1}{2}\rho_0\overline{v^2}\,, \tag{21}$$

it follows that Eq. (17) can be written

$$-\,d\,(\overline{\Delta p} - \bar{e}_p) = d\bar{e}_k \tag{22}$$

and an integration gives the "dynamic relation"

$$\overline{\Delta p} = C + \bar{e}_p - \bar{e}_k \tag{23}$$

in which C has the same value at all points of the space occupied by the fluid. This constant C disappears when the difference in pressure between two points of the fluid is computed, and as a result Eq. (23) has been widely used to compute the forces acting on solid bodies completely immersed in a vibrating fluid.[14,15] It can also be applied to the case of a steady-flow motion, and leads then directly to Bernoulli's theorem.

Absolute Value of the Acoustic Radiation Pressure

11. By using the static relation (16) the value of the constant C in the dynamic relation (23) can be computed from the boundary conditions of the fluid. To that effect the radiation pressure $\overline{\Delta p}$ is first eliminated between the two relations. This gives:

$$C = c^2\overline{\Delta\rho} - (3 - 2D)\,\bar{e}_p + \bar{e}_k \tag{24}$$

Let us now introduce an arbitrary volume V limited by a surface S fixed in space and completely immersed in the fluid. When Eq. (24) is integrated over the volume, the integration of $\overline{\Delta\rho}$ will give the average mass increase $\overline{\Delta M}$ caused by the motion in this volume V. Denoting the total potential and kinetic energies by $\overline{E}_p$ and $\overline{E}_k$ we have:

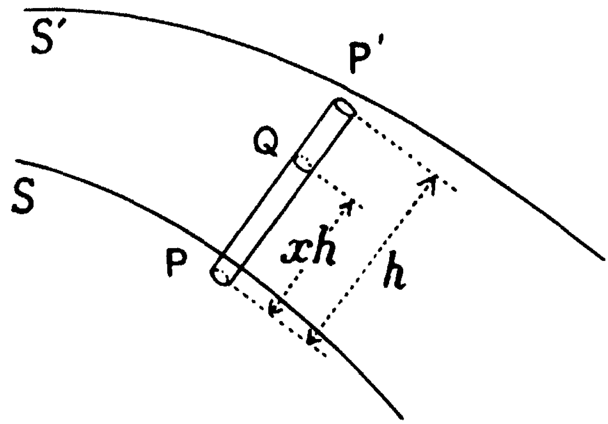
$$C = \frac{1}{V}\left[\,c^2\overline{\Delta M} - (3 - 2D)\,\overline{E}_p + \overline{E}_k\,\right] \tag{25}$$

12. The average mass increase $\overline{\Delta M}$ in Eq. (25) can be computed from the conditions at the boundary S of the volume V. The particles which lie on S in the reference state of the fluid are on a surface S' at the instant t. Let h be the distance from a point P of S to the point P' of S' situated on the same normal to S, the positive sense on this normal being toward the outside of the volume V (see Fig. 1).

Let ρ be the density at the same point P on the surface S. Then the average mass increase $\overline{\Delta M}$ is given by the approximation formula

$$\overline{\Delta M} = -\int_S \overline{\rho h} dS \tag{26}$$

which applies exactly to all terms of the first and second degree with respect to the amplitude A, but not to terms of higher degree.



13. The calculations leading to Eq. (26) illustrate the statement made in Par. 4 about the necessity of discussing carefully the degree of approximation achieved in each case. Referring to Fig. 1 again, let xh be the distance from an element Q of the cylinder of base dS and height h to the surface S, x being a dimensionless number less than unity. Then the mass contained in the cylinder is

$$dM = dS \int_0^1 \rho_Q h dx \tag{27}$$

$$= hdS \int_0^1 \rho_Q dx \tag{28}$$

We can expand ρ_Q as:

$$\rho_Q = \rho + \frac{\partial \rho}{\partial n} hx + \ldots \tag{29}$$

in which ρ is the density at the point P and $\partial\rho/\partial n$ the derivative of this function ρ along the normal to S. Now ρ can be expanded in terms of the amplitude A, according to the formula:

$$\rho = \rho_0 + \rho_1 (x, y, z, t) A + \ . \ . \ . \tag{30}$$

in which ρ_0 is independent of x, y, z, and t since the external field is negligible as stated in Par. 10. Therefore $\partial\rho/\partial n$ will start with a term of the first degree in A and we have

$$\rho_Q = \rho + \frac{\partial \rho_1}{\partial n} Ahx + \ . \ . \ . \tag{31}$$

By use of this relation, Eq. (28) yields, after integrating,

$$dM = \left(h\rho + \tfrac{1}{2} h^2 \frac{\partial \rho_1}{\partial n} A + \ . \ . \ . \right) dS \tag{32}$$

From Eq. (4) it follows that the series expansion of h starts with a term of the first degree. Therefore the second term in the parenthesis is of the third degree in A and can be neglected. The mass of the elementary cylinder can therefore be written as merely equal to $h\rho$, which leads directly to Eq. (26), giving the average mass increase $\overline{\Delta M}$ in the volume V.

NOTE: Owing to a compensation which develops when the integration is carried out over the whole surface S it is permissible to use the normal component ξ_n of the displacement of the fluid particles, or the normal component $(\xi_b)_n$ of the displacement of each point of the boundary, instead of the normal distance h in all relations starting from Eq. (26).

Practical Applications

14. Summarizing Eqs. (23), (25), and (26) the acoustic radiation pressure can be expressed by the formula:

$$\overline{\Delta p} = \frac{1}{V} \left[c^2 \overline{\Delta M} - (3 - 2D) \bar{E}_p + \bar{E}_k \right] + \bar{e}_p - \bar{e}_k \tag{33}$$

with

$$\overline{\Delta M} = - \int_S \overline{\rho h} dS \tag{34}$$

In this equation the various energies E_p, E_k, e_p, e_k, when terms of degree higher than the second are disregarded, depend only on the first order terms in the expansion of the displacement, according to Eq. (4). Therefore all these energies can be computed from the well-known wave equation which governs the first-order terms in the series expansion of the displacement. This wave equation is best written by using the velocity potential φ, and then takes the form:

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} = \frac{1}{c^2} \frac{\partial^2 \varphi}{\partial t^2} \tag{35}$$

The situation is different, however, in the case of the mass increase $\overline{\Delta M}$ appearing in the first term of Eq. (33). The displacement h of the boundary is of the first order in A but the density contains a constant term ρ_0, and we can write Eq. (34) in the form:

$$\overline{\Delta M} = - \int_S (\rho_0 + \rho_1 A + \ . \ . \ .)\,(h_1 A + h_2 A^2 + \ . \ . \ .)\, dS \tag{36}$$

From this relation it is apparent that a first-order approximation will be satisfactory as far as the density ρ is concerned; but since the second-order term in h combines with ρ_0, this term must be known exactly if the desired second-order approximation is to be obtained for $\overline{\Delta M}$ and, consequently, for the radiation pressure $\overline{\Delta p}$. The wave equation (35), therefore, is not in general sufficiently accurate to be used in computing the absolute value of the acoustic radiation pressure.

15. There are cases, however, in which it is not necessary to solve any wave equation in order to know the displacement h of the boundaries. One of these is when the boundaries are made of some solid material subjected artificially to a motion practically independent of the reaction of the fluid: a sounding pipe closed by a piston to which a heavy balance-wheel imposes a well defined oscillatory motion offers such a situation. In that case h is exactly known, and solving the first-order wave equation (35) will be sufficient to obtain the first-order terms needed in Eq. (36) to express the density ρ. The motion of a fluid enclosed within rigid, stationary walls also belongs in the same class: in that case h is identically zero and therefore ΔM is zero. Only the energy terms are left in Eq. (33) for the radiation pressure, which becomes:

$$\overline{\Delta p} = \frac{1}{V}\left[(2D - 3)\,\bar{E}_p + \bar{E}_k\right] + \bar{e}_p - \bar{e}_k \tag{37}$$

NOTE: In the particular case of plane simple-harmonic standing waves filling entirely a rigid tube closed at both ends, the quotients $\bar{E}_p/V$ and $\bar{E}_k/V$ are both equal to $\frac{1}{2}(\bar{e}_k)_{max}$, since the distribution of energy is sinusoidal. At a node of pressure, $\bar{e}_p$ is then zero while $\bar{e}_k$ is a maximum. Equation (37) then yields for the radiation pressure at the nodes:

$$\overline{\Delta p} = (D - 2)\,(\bar{e}_k)_{max} = (D - 2)\,(\bar{e}_p)_{max} = \frac{D - 2}{4}\,\frac{(\Delta p_{max})^2}{k} \tag{38}$$

If a small orifice is made in the walls of the tube at this node of pressure, a certain volume V of fluid will go in or out according to the sign of $\overline{\Delta p}$, and we have the relation:

$$\frac{\Delta V}{V} = -\frac{\overline{\Delta p}}{k} = \frac{2-D}{4}\left(\frac{\Delta p_{\max}}{k}\right)^2 = \frac{2-D}{4}(\theta_{\max})^2 \qquad (39)$$

in which θ is the dilatation. In the case of a gas the maximum dilatation $\theta_{\max}$ can be made fairly large and it might be feasible to test this relation experimentally.

16. Another case in which the first-order approximation given by the wave equation (35) is sufficient to calculate the acoustic radiation pressure is when an acoustic experiment is made in a very large space with absorbing walls so that the only important part of the phenomenon is in the relatively small portion of the space in which the instruments are located. Then Eq. (33) reduces to

$$\overline{\Delta p} = \bar{e}_p - \bar{e}_k \qquad (40)$$

This can be seen by referring to Eqs. (23) and (25): The constant C in Eq. (23) is given by Eq. (25) and can be written

$$C = c^2(\overline{\Delta\rho})_{\text{av.}} - (3 - 2D)\,(\bar{e}_p)_{\text{av.}} + (\bar{e}_k)_{\text{av.}} \qquad (41)$$

the subscript "av." meaning average over the volume V. In a very large space all these averages are zero as long as the waves are not reverberated into some troublesome standing pattern. In this respect it should be observed that absorbing walls can always be replaced by solid surfaces subjected, artifically if need be, to a suitable motion, so that the theory developed here automatically applies.

The Mass-Energy Relation

17. Expression (33) for the acoustic radiation pressure can be written in another form in which all terms can be calculated from the first-order approximation represented by the wave equation (34). This is achieved by selecting an equilibrium state of suitable properties. In Eq. (4) for the displacement there is no assumption concerning the equilibrium state. In all mechanical problems the equilibrium state is primarily a reference state and is selected merely for convenience. In the present case it need not be the same for all the motions of the family (that is, for all values of the amplitude A). Not only the equilibrium density ρ_0 may vary, but also the shape of the container and therefore the relative positions of the particles. This being so, let us define a "fundamental equilibrium state" by the condition that the average value of the displacement h of the bound-

aries during the motion, as defined in Par. 14, be zero. In other words, let the reference state be defined by the average position of the boundaries. Then it can be shown (see Appendix) that the average mass increase m, with respect to the fundamental state, is given by the mass-energy relation:

$$\tfrac{1}{2} mc^2 = \bar{E}_p - \bar{E}_k \tag{42}$$

Using this expression in Eq. (33) we obtain the following expression for the acoustic radiation pressure, with respect to this fundamental state:

$$\bar{p} = 1/V\,[(2D - 1)\,\bar{E}_p - \bar{E}_k] + \bar{e}_p - \bar{e}_k \tag{43}$$

This involves only the potential and kinetic energies and can therefore be calculated from the wave equation (35) for the first-order terms of the displacement. This is not in disagreement with the conclusions of Par. 14, but merely a different way of expressing these conclusions. It is now necessary to find the average position of the boundaries to a second-order approximation, and a discussion of this problem leads to the same results as stated in Pars. 14 and 15.

18. The derivation of the mass-energy formula (42) is given in the appendix. This formula can also be checked in cases simple enough for a complete theoretical treatment: the simplest case is that of a rigid container communicating with a cylinder in which a piston is subjected to a motion that is infinitely slow, but otherwise arbitrary; in that case there is no kinetic energy and the potential energy per unit volume is the same at all points. We have also treated the most general case of plane waves in a sound pipe, the case of progressive spherical waves, and finally, several cases of standing spherical waves. In all these cases the mass increase m was computed from the displacement and the dilatation at the boundaries of the fluid, using Eq. (26). These computations are interesting but too lengthy to be reproduced here.

Order of Magnitude of the Acoustic Radiation Pressure

19. The variation of the acoustic radiation pressure from one point to another is always a second-order quantity, according to Eq. (23). The absolute values, however, according to Eqs. (33) and (36), are in general of the first-order with respect to the amplitude A. They become of the second-order if the equilibrium state is defined by the average position of the boundaries, to the first-order approximation given by the wave equation (35), since the coefficient h_1 is then zero in Eq. (36). If this same definition of the equilibrium state is carried out to a higher degree of approximation, then the acoustic radiation pressure is not only *a* quantity of the second-order but *the* quantity

defined by Eq. (43). It can be shown that when the equilibrium state is changed so that the equilibrium pressure changes from p_0 to $p_0 + \delta p_0$, the formulas derived in this paper all lead to a radiation pressure $\overline{\Delta p} - \delta p_0$, as should be expected.

Average Pressure on a Moving Boundary

20. The acoustic radiation pressure $\overline{\Delta p}$ has been defined as the average change in pressure at a point fixed in space. If ξ_b is the displacement of an element of the boundary, and $\overline{\Delta p_b}$ the change in pressure on this element, with respect to the reference pressure, we have:

$$\overline{\Delta p_b} = \overline{\Delta p} + \overline{\text{grad } p \cdot \xi_b} = \overline{\Delta p} - \rho \overline{\frac{\partial v}{\partial t} \cdot \xi_b} \tag{44}$$

in which $\overline{\Delta p}$ is the change in pressure at the point of reference. Integrating by parts gives

$$\overline{\Delta p_b} = \overline{\Delta p} - \frac{1}{t} \rho \left| v \cdot \xi_b \right|_o^t + \rho \overline{v \cdot v_b} \tag{45}$$

The second term on the right-hand side is zero since both v and ξ_b are limited quantities, and therefore we are left with:

$$\overline{\Delta p_b} = \overline{\Delta p} + \rho \overline{v \cdot v_b} \tag{46}$$

When the motions of the walls and of the fluid are identical, the corrective term is twice the kinetic energy $\bar{e}_k$ per unit volume. If either v or v_b is normal to the surface of the boundary, the scalar product $v \cdot v_b$ is the square of the normal velocity. If the boundary is stationary, there is no correction to be made, no matter what the tangential velocity of the fluid may be.

21. As an illustration, let us consider the case of a single progressive plane wave traveling in a pipe. This case can be idealized by imagining two oscillating pistons, one at each end of the pipe, with motions identical to those of the progressive wave. Since the potential and kinetic energies are equal in this type of wave, and have the same value at all points, Eq. (43) reduces to:

$$\overline{\Delta p} = 2\,(D - 1)\,\bar{e}_k \tag{47}$$

which is the value of the average pressure on the stationary walls. From this the average pressure $\overline{\Delta p_b}$ on the pistons is calculated by using Eq. (46), which gives:

$$\overline{\Delta p_b} = 2D\bar{e}_k \tag{48}$$

These results can easily be checked by using the complete solution already described in Paragraph 5.

Appendix

The mass-energy relation (42) can be derived by starting from the expression for the kinetic energy $\overline{E}_k$ in terms of the velocity potential

$$\overline{E}_k = \frac{1}{2}\rho_o \int_V \overline{\left[\left(\frac{\partial\varphi}{\partial x}\right)^2 + \left(\frac{\partial\varphi}{\partial y}\right)^2 + \left(\frac{\partial\varphi}{\partial z}\right)^2\right]} dV \tag{49}$$

in which V is the volume enclosed by the surface S, and dV any element of this volume. This expression can be written

$$\overline{E}_k = \frac{1}{2}\rho_o \int_V \overline{div\left(\varphi\frac{\partial\varphi}{\partial l}\right)} dV - \frac{1}{2}\rho_o \int_V \overline{\varphi\nabla^2\varphi}\, dV \tag{50}$$

in which ∂l stands for any linear element. Converting the first integral into a surface integral and transforming the second by using the wave equation (35), we obtain

$$\overline{E}_k = \frac{1}{2}\rho_0 \int_S \overline{\varphi\frac{\partial\varphi}{\partial n}} dS - \frac{1}{2}\frac{\rho_0}{c^2}\int_V \overline{\varphi\frac{\partial^2\varphi}{\partial t^2}} dV = I_1 - I_2 \tag{51}$$

An integration by parts gives

$$I_2 = \frac{1}{2}\frac{\rho_0}{c^2}\int_V \frac{1}{t}\left|\varphi\frac{\partial\varphi}{\partial t}\right|_0^t dV - \frac{1}{2}\frac{\rho_o}{c^2}\int_V \overline{\left(\frac{\partial\varphi}{\partial t}\right)^2} dV \tag{52}$$

In the case of an oscillatory motion the velocity potential is a limited function of the time t, since the equilibrium state has been defined by the average position of the particles. Therefore the first integral is zero. The second represents the potential energy of the fluid, so that Eq. (51) becomes, after suitable transpositions of terms,

$$\overline{E}_p - \overline{E}_k = -\frac{1}{2}\rho_0 \int_S \overline{\varphi\frac{\partial\varphi}{\partial n}} dS \tag{53}$$

In this relation $\partial\varphi/\partial n$ represents the normal component of the velocity at any fixed, geometrical point of the surface S. But it can be shown in general that such a function of a geometrical point differs from the

corresponding particle function only by quantities of orders higher than its own. Therefore, continuing to neglect all terms of order higher than the second, we have

$$\bar{E}_p - \bar{E}_k = -\frac{1}{2}\rho_0 \int_S \overline{\varphi \frac{\partial \xi_n}{\partial t}}\, dS \tag{54}$$

in which ξ_n denotes the distance traveled by the particle, normally to the surface S, from its reference position. Integrating by parts gives a zero term again as in relation (52) and we are left with

$$\bar{E}_p - \bar{E}_k = \frac{1}{2}\rho_0 \int_S \overline{\frac{\partial \varphi}{\partial t}\, \xi_n}\, dS \tag{55}$$

Now $\partial\varphi/\partial t$ can be calculated from the change in density $(\rho - \rho_0)$ since according to the wave equation (35) the first-order approximation for the dilatation of the fluid is $(\rho_0 - \rho)/\rho_0 = (\partial\varphi/\partial t)/c^2$. Eq. (55) can therefore be written

$$\bar{E}_p - \bar{E}_k = \tfrac{1}{2} c^2 \int_S \overline{(\rho_0 - \rho)\, \xi_n}\, dS \tag{56}$$

So far the displacement ξ_n and the density increase $(\rho - \rho_0)$ in this equation are not exactly the actual ones, but only the first-order approximation functions satisfying the wave equation $\nabla^2\varphi = (1/c^2)\partial^2\varphi/\partial t^2$. But the difference between the actual and approximate values is of the second-order with respect to the amplitude, and using the actual values in Eq. (56) will therefore result in an error of the third order. Finally, if the equilibrium state is defined by the average position of the walls to a second-order approximation the quantity $\overline{\rho_0 \xi_n}$ will be zero to this approximation, and the result is:

$$E_p - E_k = -\frac{1}{2} c^2 \int_S \overline{\rho \xi_n}\, dS = \frac{1}{2} mc^2 \tag{57}$$

in which m is the average mass increase in the volume V occupied by the fluid in the equilibrium state.

NOTE: We could also write in general, using, Eq. (56),

$$\frac{1}{2} c^2 \Delta M = -\frac{1}{2} c^2 \int_S \overline{\rho \xi_n}\, dS = \bar{E}_p - \bar{E}_k - \frac{1}{2}\rho_0 c^2 \int_S \overline{\xi_n}\, dS \tag{58}$$

This would make it immediately evident that ξ_n has to be known to a second-order approximation if ΔM is to be computed to this approximation. If the equilibrium state is defined by the average position of the walls, the last integral drops out and the result is again Eq. (57).

Acknowledgments

I wish to express my gratitude to Dr. Walter G. Cady, to whom I am indebted for the completeness of this paper in its final shape; to Dr. E. Hiedemann, of the Naval Ordnance Laboratory, for his kind interest and helpful criticism; and to Dr. F. Wolfers of the University of Algiers, for his friendly support at the beginning of this work.

Bibliography

The production of acoustic forces by sound waves from a vibrating source, when obstacles are placed in the path of these waves, was experimentally demonstrated in 1834 by J. Guyot.[1] Further experiments were carried out independently by A. M. Mayer[2] and V. Dvorak,[3,4] who published their results in the same year, 1876. By means of direct measurements, Dvorak showed that the average pressure of the gas in a sounding pipe is higher at a node of displacement.[3] Toward the end of the century, Lord Rayleigh derived theoretical expressions for the acoustic radiation pressure, and his results were later extended by other physicists until full generality was attained: the dynamic fundamental relation, Eq. (23), was given by P. Langevin, as quoted by P. Biquard,[12,13] while the influence of the distortion was investigated by L. Brillouin,[10,11,16,17] who gave a theory of the acoustic radiation pressure in the case of plane waves.

REFERENCES

1. J. Guyot, *L'Institut*, No. 45 (1834), see also *Ann. der Phys. und Chem.*, vol. *31*, p. 640 (1834); *Ann. de Phys. et de Chim.*, vol. *25*, pp. 199–202 (1872); *Ann. der Phys. und Chem.*, vol. *157*, p. 43 (1876).
2. A. Mayer, *Proc. of the New York Acad. of Sci.* (1876), see also *Scientific American*, vol. *35*, p. 29 (1876); *Phil. Mag.* vol. *6*, pp. 231–233 (1878).
3. V. Dvorak, *Ann. der Phys. und Chem.*, vol. *157*, pp. 42–73 (1876).
4. V. Dvorak, *Ann. der Phys. und Chem.*, vol. *3*, pp. 328–338 (1878).
5. Lord Rayleigh, "The Theory of Sound," vol. II, pp. 42–43, The Macmillan Co., London (1896).
6. Lord Rayleigh, *Phil. Mag.*, vol. *3*, p. 338 ff. (1902).
7. J. H. Poynting, *Phil. Mag.*, vol. *9*, pp. 393–406 (1905).
8. Lord Rayleigh, *Phil. Mag.*, vol. *10*, pp. 364–374 (1905).
9. W. Weaver. *Phys. Rev.*, vol. 15, pp. 399–404 (1920).
10. L. Brillouin, *Ann. de Phys.*, vol. *4*, pp. 528–586 (1925).
11. L. Brillouin, *J. de Phys.*, vol. *6*, pp. 337–353 (1925).
12. P. Biquard, *Rev. d'Acoust.*, vol. *1*, pp. 93–109 (1932).

13. P. Biquard, *Rev. d'Acoust.*, vol. *2*, pp. 315–335 (1933).
14. L. V. King, *Proc. Roy. Soc.*, vol. *147*, pp. 212–240 (1934).
15. L. V. King, *Proc. Roy. Soc.*, vol. *153*, pp. 1–16 (1935).
16. L. Brillouin, *Rev. d'Acoust.*, vol. *5*, pp. 99–111 (1936).
17. L. Brillouin, "Les Tenseurs en Mécanique et en Elasticité," Chapter XI. Dover Publications, New York, 1946.
18. J. S. Mendousse, *C. R. de L'Acad. des Sc.*, vol. *208*, pp. 1977–1980 (1939).
19. Cl. Schaefer, *Ann. der Phys.*, vol. *35*, pp. 473–491 (1939).
20. G. Hertz and H. Mende, *Zts. f. Phys.*, vol. *114*, pp. 354–367 (1939).
21. G. Richter, *Zts. f. Phys.*, vol. *115*, pp. 97–110 (1940).
22. G. Hertz, *Phys. Zts.*, vol. *41*, pp. 546–549 (1940).
23. F. von Bopp, *Ann. der Phys.*, vol. *38*, pp. 495–500 (1940).
24. Cl. Schaefer, *Zts. f. Phys.*, vol. *115*, pp. 109–110 (1940).
25. G. Hertz, *Zts. f. Tech. Phys.*, vol. *21*, pp. 298–301 (1940).
26. A. L. Thuras, R. T. Jenkins and H. T. O'Neil, *J. Acous. Soc. Am.*, vol. *6*, pp. 173–180 (1935).
27. J. Hartman and T. Mortensen, *Ingeniør-videnskabelige Skrifter*, pp. 1–65 (1948).

THERMODYNAMIC RELATIONS IN n-VARIABLE SYSTEMS IN JACOBIAN FORM: PART I, GENERAL THEORY AND APPLICATION TO UNRESTRICTED SYSTEMS

BY F. H. CRAWFORD

(*Williams College*)

Received May 7, 1949

I. INTRODUCTION

The utility of Jacobians or functional determinants in obtaining the general first derivative relations in thermodynamics has been pointed out by the author[1] and the special case of two independent variables discussed in detail.[2] The purpose of the present paper is to develop the method in terms sufficiently general to permit immediate application to the greatest diversity of physico-chemical systems. It represents essentially a unified approach to the general analytic treatment of thermodynamics and it is the method rather than the results on which any claims of novelty must rest. The method is at once so flexible and direct that it enables specific and precise relations to be written down as soon as the general expression for the differential, dU, of the internal energy of the system can be set up and a suitable set of independent variables selected. After a little practice the user will be enabled to write down the desired relations for any particular system with the minimum of intermediate equations and with as much confidence as he may copy them from tables in the few cases where they exist.[3]

The general procedure is essentially an extension to the case of n-independent variables of the results given in Part A[2]. Due to the greatly increased complexity of the expressions involved in the case of n-independent variables it will be convenient to divide all the possible systems to which classical thermodynamics applies into two groups on the basis of whether there *are* or are *not* special functional restrictions on certain variables which must be borne in mind throughout

[1] F. H. Crawford. Phys. Rev. *72*, 521A, 1947.

[2] F. H. Crawford. Am. Jour. of Physics, *17*, 1–5, 1949. This will be referred to in the sequel as part A.

[3] See P. W. Bridgman "A Condensed Collection of Thermodynamic Formulas" Harvard Press, Cambridge 1925 and R. W. Goranson "Thermodynamic Relations in multicomponent Systems" Carnegie Institution of Washington, Washington, D. C., 1930.

the discussion. All those systems where no special functional restrictions exist we shall call *unrestricted* or simply *general* systems. The present paper will be confined to these while Part II (in preparation) will discuss *restricted* systems, i. e., those systems characterized by the limited functional dependence of certain variables.

II. Notation and Variables

As in Part A where $n = 2$ we make our point of departure Clausius' combination of the Ist and IInd Laws of Thermodynamics,

$$dU = TdS + dW_c \tag{1}$$

where U and S are respectively the *internal energy* and *entropy* of the system and dW_c is the differential work performed *on* the system during the quasi-static passage along an infinitesimal length of any arbitrary curve of change c. For the simple system under hydrostatic pressure $dW_c = -pdV$, while in general it will involve more than one work term, one in fact for each generalized force acting on the system. Each of these terms will be of the form $Fd\theta$, where F is a *generalized force* (or intensity) variable and θ the corresponding or *conjugate geometric* variable. Since TdS is of the same form we may regard T, the absolute temperature, as a generalized force and S as its conjugate geometric variable. If now when dW_c is reduced to its simplest form there are $(n-1)$ work terms, i.e., $dW_c = \sum_{i=2}^{n} F_i d_i\theta$, we have for Eqn. (1)

$$dU = TdS + F_2d\theta_2 + F_3d\theta_3 + \ldots + F_nd\theta_n \tag{2}$$

or

$$dU = F_1d\theta_1 + F_2d\theta_2 + \ldots + F_nd\theta_n = \sum_{i=1}^{n} F_id\theta_i \tag{3}$$

Then Eqn. (3) (or its equivalent Eqn. (2)) is the generalized Clausius equation and holds for any reversible differential change imaginable in the system. This naturally rules out of consideration non-equilibrium systems as well as those in which hysteretic effects are significant.

Since the expression for dU is assumed reduced to the smallest number, n, of terms compatible with the nature of the system, and dU is a perfect or complete differential, n is simply the *number* of *independent variables* involved or the *total* number of degrees of freedom of the system.[4] We shall designate particular independent

[4] Here n must not be confused with what we may call the "degree of variability" as given, for example, for a chemical system by Gibbs' phase rule. The latter is the number of independent intensity (or force) variables and is in general $\leqslant n$.

variables by x's and any special set as $(x_1, x_2, \ldots x_n)$ and shall confine their choice to those in the dexter of Eqn. (3).

A glance at this equation shows that there are $2n$ such variables $(F_1, \ldots F_n, \theta_1 \ldots \theta_n)$ and these we shall call *primary* variables. The particular primaries selected for our x-set, $(x_1, \ldots x_n)$, is in practice usually dictated by experimental considerations. Thus we might desire to choose all θ's (a geometric set) or all F's (a force set) or some other combination. Examination soon reveals the fact that some types of systems permit any *arbitrary' choice* of x's we like while others do not. The first type is the *unrestricted* or *general* n-*variable* system. Such are characterized by the fact that no single primary variable depends on *less* than n others. Hence in *principle* at least the choice of an x-set is quite unrestricted. On the other hand, we have all the other systems where this is *not* true but where special restrictions on functional dependence must be borne in mind not only in selecting an x-set but in carrying out the partial differentiations concerned. This division is particularly desirable since systems of variable mass, and hence most poly-phase, poly-component chemical systems, fall in the restricted class and require special examination. Other simple examples were given in Part A (sec. VI (b)).

There are in addition to the primary variables all the subsidiary or *secondary* quantities which are either defined explicitly in terms of the primaries or their differentials. The secondaries include U itself, the enthalpy H, Helmholtz's free energy A, Gibbs' function G and a great many others of interest in particular systems. The defining relations for H, A, and G, and their corresponding differentials by use of Eqn. (3), may be written down for reference at this point. We have:[5]

$$H = U - \sum_{i=2}^{n} F_i\theta_i \text{ and } dH = TdS - \sum_{i=2}^{n} \theta_i dF_i \tag{4}$$

$$A = U - TS \quad \text{ and } dA = -SdT + \sum_{i=2}^{n} F_i d\theta_i \tag{5}$$

$$G = U - TS - \sum_{i=2}^{n} F_i\theta_i \text{ and } dG = -SdT - \sum_{i=2}^{n} \theta_i dF_i \tag{6}$$

[5] It is to be noted that except for A, these are not the definitions of H and G which are often used, viz., $U + pV$ and $U - TS + pV$, respectively. Since, however, all such potentials are in essence arrived at by subjecting dU in Eq. (3) to a *Legendre* transformation a very great number of such exist for the n variable case and there seems no particular virtue in trying to separate hydrostatic and non-hydrostatic work terms, which the conventional definitions do. In any case the same set of $2n$ primary variables results and the applications of Eq. (15) in sec. V below leads to the same relations, with either choice.

Having selected from the $2n$ original primaries a set of independent variables $(x_1, \ldots x_n)$ we have n primaries left which are then the *dependent* variables. These will be indicated by $(Y_1 \ldots Y_n)$. When we do not wish to indicate the restriction to primary variables we shall use $(X_1, \ldots X_n)$ for an independent set and Z_i for any dependent variable (where i is now no longer confined to be n or below). Thus of the two general derivatives $(\partial Y_i/\partial x_1)_{x_2 \ldots x_n}$ and $(\partial Z_i/\partial X_1)_{X_2 \ldots X_n}$, the former may involve *no* secondaries, while the latter might or might not. Thus we have:

The *primary* variables ($2n$ in number)	$(F_1, F_2, \ldots F_n, \theta_1, \theta_2, \ldots \theta_n)$
The *secondary* variables	U, H, A, G, etc.
A Primary *independent* set	$(x_1, x_2, \ldots x_n)$
A Primary *dependent* set	$(Y_1, Y_2, \ldots Y_n)$
Any independent set	$(X_1, X_2, \ldots X_n)$
Any dependent set	$(Z_1, Z_2, \ldots Z_n)$

III. Useful Properties of Jacobians

The ease of manipulation of Jacobian expressions depends among other things on certain properties among which we may list a) sign rules, b) reduction properties and c) transformation properties. Let our general n dimensional Jacobian be

$$\frac{\partial (Z_1, \ldots Z_n)}{\partial (X_1, \ldots X_n)} = \begin{vmatrix} \left(\frac{\partial Z_1}{\partial X_1}\right) & \left(\frac{\partial Z_2}{X_1}\right) & \cdots & \left(\frac{\partial Z_n}{\partial X_1}\right) \\ \vdots & \vdots & & \vdots \\ \left(\frac{\partial Z_1}{\partial X_n}\right) & \left(\frac{\partial Z_2}{\partial X_n}\right) & \cdots & \left(\frac{\partial Z_n}{\partial X_n}\right) \end{vmatrix} = J\,(Z_1, Z_2, \ldots Z_n) \quad (7)$$

where

$\left(\frac{\partial Z_1}{\partial X_1}\right)$ is short for $\left(\frac{\partial Z_1}{\partial X_1}\right)_{X_2 - X_n}$ etc. and where the J notation will be used whenever the independent variables will not be in doubt. Here and throughout we assume that there is no functional relation connecting the Z's so that J never vanishes identically.

a) *Sign Rules*

Regarding J simply as an nth order determinant the following rules governing change of sign on altering the order of any of the Z's (or X's) follow from the well known properties of determinants. They are particularly useful when reducing Jacobians to some standard form in which the order of the Z's and X's is fixed.

The sign of $J = \dfrac{\partial (Z_1, \ldots Z_n)}{\partial (X_1, \ldots X_n)}$ will be

(1) *changed* when a *neighboring* pair of Z's (or X's) is interchanged.
(2) *changed* when any pair of Z's (or X's) is interchanged provided the *order* of the rest is preserved.
(3) *unchanged* no matter what changes of order we make provided every Z appears over its original X. Thus what we may term "vertical pairs" may be moved around in any arbitrary way without any change of sign.

b) Reduction Properties

Whenever a *common* variable occurs among the Z's and X's a reduction of the *order* of the Jacobian takes place. Thus in Eqn. (7) suppose that $Z_1 = X_1$. Then the first column reduces to unity followed by a string of zeros. Hence on expanding by minors and elements of this column we have only *one* term, the minor after suppressing the first row and column. Hence formally we may *cancel* X_1,

$$\frac{\partial (X_1, Z_2, \ldots Z_n)}{\partial (X_1, X_2, \ldots X_n)} = \frac{\partial (Z_2, \ldots Z_n)}{\partial (X_2, \ldots X_n)_{X_1}}$$

with the proviso that X_1 is written outside since it must remain constant throughout. When the common elements are not a vertical pair they may always be cancelled with a sign alteration after interchanging the appropriate Z's (by sign rule a-2 above).

Similarly all common pairs may be so cancelled until if there be $(n - 1)$ such, we have J reduced to a *single* derivative. Thus

$$\frac{\partial (X_1, X_2, X_3, \ldots X_{n-1}, Z_n)}{\partial (X_1, X_2, X_3 \ldots X_{n-1}, X_n)} = \left(\frac{\partial Z_n}{\partial X_n}\right)_{X_1 X_2 \ldots X_{n-1}} \tag{8}$$

and a partial derivative may then be regarded as simply an nth order Jacobian reduced by cancellation to the first order.

This process may of course be reversed; we then "expand" a first order derivative into an nth order Jacobian (see section IV below).

c) General Transformation Properties of Jacobians

The chief reason for the utility of Jacobians in the present connection lies in the ease and flexibility of their transformations. The Jacobian of Eqn. (7) involves n^2 derivatives with $(X_1, X_2 \ldots X_n)$ as the independent set. If we wish to express this Jacobian in terms of a new special set $(x_1 \ldots x_n)$ of *primary* variables, in terms of which all the Z's and X's are regarded as defined, we have by the well known theorem:

$$\frac{\partial (Z_1, \ldots Z_n)}{\partial (X_1, \ldots X_n)} = \frac{\dfrac{\partial (Z_1, \ldots Z_n)}{\partial (x_1, \ldots x_n)}}{\dfrac{\partial (X_1, \ldots X_n)}{\partial (x_1, \ldots x_n)}} = \frac{J (Z_1, \ldots Z_n)}{J (X_1, \ldots X_n)} \tag{9}$$

Here it is quite important that we write the theorem as the *ratio* of two Jacobians—since in this case both $J(Z_1 \ldots Z_n)$ and $J(X_1 \ldots X_n)$ are in terms of the *same* independent variable set $(x_1 \ldots x_n)$. If we use the mathematically identical (and usually quoted) form of the *product* of the two Jacobians, i. e., $J(Z_1 \ldots Z_n) \times J(x_1 \ldots x_n)$, then the first Jacobian is in terms of the independent set $(x_1 \ldots x_n)$ while the second employs $(X_1 \ldots X_n)$ and the utility of the transformation for our application is greatly lessened.

IV. General Derivative as a Ratio of Two Jacobians

We may now combine the theorem given in Eqn. (9) with the expansion of an arbitrary derivative, Eqn. (8), and have our general result. Thus, given a derivative $\left(\dfrac{\partial Z}{\partial X_1}\right)_{X_2 \ldots X_n}$, we express it as the ratio of two separately computable (i. e., essentially independent) Jacobians involving the primary set $(x_1 \ldots x_n)$ as independent variables. We have, expanding the derivative and using Eqn. (9):

$$\left(\frac{\partial Z}{\partial X_1}\right)_{X_2 \ldots X_n} = \frac{\partial (Z, X_2 \ldots X_n)}{\partial (X_1, X_2 \ldots X_n)} = \frac{\dfrac{\partial (Z, X_2, \ldots X_n)}{\partial (x_1, x_2 \ldots x_n)}}{\dfrac{\partial (X_1, X_2 \ldots X_n)}{\partial (x_1, x_2 \ldots x_n)}}$$

$$= \frac{J (Z, X_2, \ldots X_n)}{J (X_1, X_2, \ldots X_n)} \tag{10}$$

Having selected a set of x's we shall suppose that they are written in the order $(x_1 \ldots x_n)$ in which they occur in Eqn. (3) read left to right. Then the remaining primaries are Y's and are to be arranged in a similar order $(Y_1 \ldots Y_n)$. Then form the Jacobian J_0

$$J_0 \equiv \frac{\partial (Y_1, \ldots Y_n)}{\partial (x_1, \ldots x_n)} \tag{11}$$

If we call this the *fundamental Jacobian* for the system (its form of course varying with the particular x selection made), we have the

theorem: "Any arbitrary derivative $\left(\dfrac{\partial Z}{\partial X_1}\right)_{x_2 \ldots x_n}$ may be expressed as the ratio of two Jacobians which will never involve derivatives other than the n^2 contained in the fundamental Jacobian, J_0."

To prove this we shall suppose first that the $(n + 1)$ variables in $(\partial Z/\partial X_1)x_2 \ldots x_n$ are all primaries. Now select any n primaries as our x-set. Then since there are only $2n$ primaries all told there must be at *least one* common member in the x-set and set $(Z\ X_2 \ldots X_n)$ or set $(X_1 \ldots X_n)$. Hence there will be at least one cancellation in one of the Jacobians of (10). Suppose it is Z which cancels X_1 (it is really immaterial). Then all the derivatives in $J\ (X_2 \ldots X_n)x_1$ occur in $J\ (X_1, X_2 \ldots X_n)$. Since there are only n dependent variables the set $(X_1 \ldots X_n)$ must except for possible difference of order be $(Y_1 \ldots Y_n)$. Hence no derivatives occur in Eqn. (10) which are not in J_0.

Now suppose any one of the set $(Z, X_1, X_2 \ldots X_n)$ contained in our derivative is a *secondary* variable. For definiteness let it be Z again—then the first column of our top Jacobian will include all the derivatives of Z with respect to $(x_1 \ldots x_n)$. But since Z is expressed in terms of primary variables only, no new derivatives (i. e., not contained in J_0) can arise, though of course the primaries themselves may be involved. Hence the theorem.

V. Maxwell's $\dfrac{n(n-1)}{2}$ Relations

Thus far we have used purely mathematical transformations and Eqn. (3) has been used only in so far as it fixed the primary variables involved. We now need the most general analytical consequences of the thermodynamic truth contained in this equation. If we take this truth to be the fact that dU is a perfect or exact differential, then the conditions of exactness lead to precisely the type of results we need. But these may be written down at once by equating cross derivatives taking the terms in Eqn. (3) in pairs. This gives us for example $\left(\dfrac{\partial F_1}{\partial \theta_2}\right)_{\theta_1, \theta_3 \ldots \theta_n} = \left(\dfrac{\partial F_2}{\partial \theta_1}\right)_{\theta_2 \ldots \theta_n}$, etc. Since there are obviously $\dfrac{n\ (n-1)}{2}$ such pairs (since the order of the pairs is immaterial) we must have $\dfrac{n\ (n-1)}{2}$ such equations. This set of $\dfrac{n\ (n-1)}{2}$ independent equations constitutes in fact Maxwell's

general relations for the particular x-set $(\theta_1 \ldots \theta_n)$. Since, however, we need them in the form suitable for *any* x-set this general form must now be found. This is perhaps most simply done by returning to Eqn. (3) and expressing each $d\theta$ in terms of $dx_1 \ldots dx_n$ since for each θ, $\theta = \theta(x_1 \ldots x_n)$. Making this substitution and collecting terms we have (omitting the variables held constant in each derivative)

$$dU = \sum_{i=1}^{n} F_i \left(\frac{\partial \theta_i}{\partial x_1}\right) dx_1 + \sum_{i=1}^{n} F_i \left(\frac{\partial \theta_i}{\partial x_2}\right) dx_2 + \ldots \qquad (12)$$

Now we apply the conditions of exactness to the coefficient of the dx's taken in pairs just as before. Thus for the first pair on differentiating and regrouping the uncancelled terms

$$\sum_{i=1}^{n} \left[\left(\frac{\partial F_i}{\partial x_1}\right)\left(\frac{\partial \theta_i}{\partial x_2}\right) - \left(\frac{\partial F_i}{\partial x_2}\right)\left(\frac{\partial \theta_i}{\partial x_1}\right)\right]_{x_3 \ldots x_n} = \sum_{i=1}^{n} \frac{\partial (F_i, \theta_i)}{\partial (x_1, x_2)_{x_3 \ldots x_n}} = 0 \qquad (13)$$

or in condensed form:

$$J(F_1, \theta_1)_{x_3 \ldots x_n} + J(F_2, \theta_2)_{x_3 \ldots x_n} + J(F_3, \theta_3)_{x_3 \ldots x_n} + \ldots = 0 \qquad (14)$$

But this states simply that Maxwell's first relation is equivalent to the vanishing of n second order Jacobians in each of which $(x_3 \ldots x_n)$ are held constant. Unfortunately, such a relation is too complicated to be readily solved for any particular derivative. We note, however, that the arguments in the Jacobian are simply the *conjugate* pairs (F_1, θ_1) (F_2, θ_2), etc., as they occur in Eqn. (3). This suggests at once that we put a restriction on the choice of the set $(x_1 \ldots x_n)$, namely, permit it to contain *no conjugate* variables, i. e., pairs of the same subscript such as F_1 and θ_1, etc. The reduction ensuing is remarkable. In the first place $J(F_3, \theta_3)_{x_3 \ldots x_4} = 0$ since x_3 must either be F_3 or θ_3, and every reduced Jacobian vanishes, whenever, any variable outside the bracket also occurs in the numerator. Likewise $J(F_4, \theta_4)_{x_3 \ldots x_n} = 0$ since x_4 is either F_4 or θ_4, etc., for all the other terms. In the second place the first two Jacobians which are all that remain, must each reduce by cancellation to a *single* derivative. For since x_1 is either F_1 or θ_1 one of these cancels, and x_2 being F_2 or θ_2 one of these likewise goes out. We are not able, however, to perform this cancellation until the actual explicit choice of x's is made. Hence we must write as the general form of Maxwell's first relation simply:

$$\frac{\partial (F_1, \theta_1)}{\partial (x_1, x_2)_{x_3 \cdots x_n}} + \frac{\partial (F_2, \theta_2)}{\partial (x_1, x_2)_{x_3 \cdots x_n}} = 0 \tag{14}$$

Here the Jacobians which do not vanish identically contain only (F_1, θ_1) and (F_2, θ_2) written in just the order they occur in Eqn. (3). We may then likewise write those from dx_1 and dx_3 as

$$\frac{\partial (F_1, \theta_1)}{\partial (x_1, x_3)_{x_2, x_4 \cdots}} + \frac{\partial (F_3, \theta_3)}{\partial (x_1, x_3)_{x_2, x_4 \cdots}} = 0;$$

from dx_2 and dx_3 as

$$\frac{\partial (F_2, \theta_2)}{\partial (x_2, x_3)_{x_1, x_4 \cdots}} + \frac{\partial (F_3, \theta_3)}{\partial (x_2, x_3)_{x_1, x_4 \cdots}} = 0;$$

. . . .

or in general terms

$$\frac{\partial (F_j, \theta_j)}{\partial (x_j, x_k)x_i \cdots} + \frac{\partial (F_k, \theta_k)}{\partial (x_j, x_k)x_i \cdots} = 0 \quad \begin{array}{l} j = 1, 2, \ldots n \\ j \neq k \\ i \text{ takes all values except } j \text{ and } k. \end{array} \tag{15}$$

The $\frac{n(n-1)}{2}$ equation contained in Eqn. (15) are Maxwell's relations in their most general form for the case of $(x_1 \ldots x_n)$ being *non-conjugate* primary variables.[6] In all cases the relations of Maxwell connect elements on *one* side of the positive diagonal of J_0 with their conjugate elements on the other side, in fact the conjugates are always either equal in pairs or differ only in sign.[7] Consequently of the n^2 original derivatives or elements in J_0, $\frac{n(n-1)}{2}$ may be eliminated, leaving us $n^2 - \frac{n(n-1)}{2}$ or $\frac{n(n+1)}{2}$ as the irreducible number in terms of which any other derivative can be expressed by means of Eqn. (10). Of course in many cases there will be a good deal of reduction in the two Jacobians involved—but no *more* than $\frac{n(n+1)}{2}$ need ever occur. Hence the final result: "*Any given derivative,*

[6] This result is quite similar to the one given for $n = 2$, Part A, sec. III (b) but the author has been unable to deduce it by such a concise method.

[7] The term conjugate is used in two senses, one referring to conjugate *variables* in Eqn. (3), i. e., variables from the same term $F_i d\theta_i$ and conjugate *elements* in a determinate, i. e., element pairs which are symmetrically placed with respect to the main diagonal.

$\left(\frac{\partial Z}{\partial X_1}\right)_{X_2 \ldots X_n}$, *can be expressed as the ratio of two separately computable Jacobians which will not involve more than* $\frac{n(n+1)}{2}$ *members of a standard set of derivatives.*"

It is clear that this standard set of derivatives must always contain the n elements *on* the positive diagonal of J_0 together with $\frac{n(n-1)}{2}$ off-diagonal elements (and not, of course, including any conjugate pairs). Just which are selected for the standerd set depends on convenience (usually experimental) though the terms in Eqn. (3) may often be arranged so as to have the standard set *on* and *above* the positive diagonal. It will be noted that there are precisely $\frac{n(n+1)}{2}$ elements in such a triangular array and once the elements of such an array are determined experimentally, all other derivatives are in theory fixed. Since this triangular array is really the functional *Pfaffian* of the dependent with respect to the independent variables, we may for brevity refer to this array simply as the Pfaffian of J_0. No reference is intended to the actual magnitude of the Pfaffian as an algebraic quantity, since in our reckoning square arrays only may arise. On this basis restricted systems will be seen to differ from the general unrestricted ones chiefly in the fact that for them one or more elements of the Pfaffian of J_0 must vanish.

VI. Summary of Method for Unrestricted Systems

Although the above treatment covers the unrestricted system where primary variables offer suitable x-sets, there are a number of points which in practice greatly simplify the whole discussion.

The simplest case arises when all the terms in Eqn. (3) are *positive* and we choose the x set as *all* F's or *all* θ's. In these cases Eqns. (15) become, respectively,

$$\left(\frac{\partial \theta_j}{\partial F_k}\right)_{F_i} = \left(\frac{\partial \theta_k}{\partial F_n}\right)_{F_i} \tag{16}$$

and

$$\left(\frac{\partial F_j}{\partial \theta_k}\right)_{\theta_i} = \left(\frac{\partial F_k}{\partial \theta_j}\right)_{\theta_i} \qquad \begin{array}{l} j \neq k \\ i \text{ includes all integers but } j \text{ and } k \end{array} \tag{17}$$

But this means that, with either choice, J_0 will be *symmetric* about the main diagonal. To be specific let the x's be *all* forces (when writing S for θ, and T for F_1) we have for J_0

$$J_0 \equiv \frac{\partial\,(S, \theta_2, \ldots \theta_n)}{\partial\,(T, F_2, \ldots F_n)}$$

$$\text{or}\quad J_0 \equiv \begin{vmatrix} \dfrac{\partial S}{\partial T} & \dfrac{\partial \theta_2}{\partial T} & \dfrac{\partial \theta_3}{\partial T} & \cdots & \dfrac{\partial \theta_n}{\partial T} \\ \dfrac{\partial S}{\partial F_2} & \dfrac{\partial \theta_2}{\partial F_2} & \dfrac{\partial \theta_3}{\partial F_2} & \cdots & . \\ \dfrac{\partial S}{\partial F_3} & \dfrac{\partial \theta_2}{\partial F_3} & \dfrac{\partial \theta_3}{\partial F_3} & \cdots & . \\ . & . & . & \cdots & . \\ \dfrac{\partial S}{\partial F_n} & . & \cdots & & \dfrac{\partial \theta_n}{\partial F_n} \end{vmatrix} = \begin{vmatrix} a_0 & a_1 & a_2 & \cdots & a_m \\ a_1 & a_{11} & a_{12} & \cdots & a_{1m} \\ a_2 & a_{12} & a_{22} & \cdots & a_{2m} \\ . & . & . & \cdots & . \\ a_m & . & \cdots & & a_{mm} \end{vmatrix} \equiv \Delta_0$$

Here the two square arrays one of derivatives and the other of coefficients $a_0 \ldots a_{mm}$ (with $m = n - 1$) serve as a convenient tabular display giving us Maxwell's relations at a glance as well as a concise set of abbreviations for the derivatives proper.[8] The derivatives naturally break up into two groups, the first column being calorimetric derivatives and the rest of the first row thermal dilations. All of the former except $(\partial S/\partial T)$,[9] are equal by symmetry to corresponding members of the latter group; since the thermal dilations are usually more readily measured they are usually retained and the coefficients in Δ_0, $a_1 \ldots a_m$, would accordingly be taken as representing generalized thermal dilations. The remaining square array of m^2 *isothermal* derivatives are reduced by symmetry to $m\,(m + 1)/2$ independent generalized isothermal elastic strain coefficients. Just which of an equal pair is to be eliminated in practice depends on circumstances and the method of writing Δ_0 leaves the choice of course open.

As we pass from systems with small values of n to more complicated ones a new and longer column is added to the Pfaffian for each unit increase in n, as the table below shows. In the first column is the value of n, in the second the number of independent coefficients in the fundamental set (or in the Pfaffian of J_0) and in the third a typical example. Of these the case of $n = 2$ has been considered in Part A and for the last three it will be sufficient for our purposes to set up J_0 or its equivalent as an indication of both the closed nature of the analysis and of the way in which the results of more specialized treatments are summarized in the general case.

[8] When it is necessary to distinguish between the two square arrays as such, J_0 and Δ_0 will be used.

[9] Since this is $(\partial S/\partial T)_{F_2 \ldots F_n}$, a_0 is the heat capacity of the system at constant $F_2 \ldots F_n$ divided by the *absolute* temperature.

TABLE

n	Derivatives in Pfaffian	Typical System (unrestricted)
2	3	Pure substance under hydrostatic pressure
3	6	Uniform Rod under Tension and pressure
4	10	Triclinic crystal in a uniform Electric field
7	28	Triclinic crystal under uniform general stress
10	55	Triclinic crystal under stress and Electric field

It is of course an advantage to have the fundamental Jacobian symmetric since this means that we may write down Maxwell's relations directly by equating conjugate derivatives without using Eqns. (15,) (16) or (17) at all. There are two remaining cases, which include the most important practical situations, where the symmetry may be retained by a simple rule of signs. Thus whenever any term in Eqn. (3) appears with a *minus* sign we insert a *minus* sign in front of the independent variable in J_0. (The most common case of course is that of the hydrostatic term occurring as $-pdV$.) Further, if for some reason we must depart from all-force or all-geometric variables, i. e., use a "mixed" set of primaries, we may preserve our symmetry by introducing a *minus* sign in front of any independent variable (in J_0) whose order in the terms $Fd\theta$ is *opposite* that of the order established in selecting from F_1 and θ_1 in $F_1\,d\theta_1$. Thus if we take for our x-set the first variable in the first term of Eqn. (3), i. e., F_1, but select the *second* (θ_2) in the second, $F_2\,d\theta_2$, we must put a minus sign in front of θ_2 in J_0.[10] Obviously, if we are using all force variables except in a hydrostatic term where we choose V instead of p, the two sign changes cancel and $+V$ is used in J_0. These sign rules will become somewhat clearer after the first example below has been discussed.

Before beginning the examples, one further remark should be made. The whole of the discussion so far could have, with equal ease, been based on the equation for dH, dA or dG, Eqns. (4), (5) or (6). Thus each gives the same set of primaries for the problem. Further, if we apply Maxwell's relations in the general form of Eqn. (15) we obtain precisely the same results, provided that the terms $F_i\,d\theta_i$ or $\theta_i\,dF_i$ are written in the same order as in Eqn. (3). This results from the fact that $J(F_i, \theta_i) = -J(\theta_i, F_i)$ and that the terms in the four Eqns.

[10] It really is not important whether the minus sign occurs before the dependent or the independent variable since in either case we change the sign of all the elements in a row or column and the formal symmetry of the Jacobian is preserved.

(3) to (6) are in fact always identical except when force and geometric variables are interchanged (when minus signs always occur).

VII. Examples

Of the unrestricted systems met in practice, probably the most common is that for $n = 3$, and it will be treated at slightly more length than the others.

a) $n = 3$ *Thin rod under pressure and tension*

Given a thin rod of volume V and length L which is under both uniform hydrostatic pressure p and an extensive force F (gravitational effects being neglected). Eqn. (3) becomes

$$dU = TdS - pdV + FdL \tag{19}$$

where we have the 6 primary variables (T, S, p, V, F, L) any three of which we may in theory take as independent. If we choose (T, p, F) for our x-set we should then write

$$J_0 \equiv \frac{\partial\,(S, V, L)}{\partial\,(T, -p, F)} \equiv \begin{vmatrix} \dfrac{\partial S}{\partial T} & \dfrac{\partial V}{\partial T} & \dfrac{\partial L}{\partial T} \\ -\dfrac{\partial S}{\partial p} & -\dfrac{\partial V}{\partial p} & -\dfrac{\partial V}{\partial p} \\ \dfrac{\partial S}{\partial F} & \dfrac{\partial V}{\partial F} & \dfrac{\partial V}{\partial F} \end{vmatrix} = \begin{vmatrix} a_0 & a_1 & a_2 \\ a_1 & a_{11} & a_{12} \\ a_2 & a_{12} & a_{22} \end{vmatrix} \equiv \Delta_0 \tag{20}$$

where the $(-p)$ is used to preserve the symmetry of J_0 and give us the reciprocal relations directly on equating conjugate derivatives (as $\left(\dfrac{\partial V}{\partial T}\right)_{pF} = -\left(\dfrac{\partial S}{\partial p}\right)_{TF}$, etc.) Here the a's are abbreviations for the corresponding derivatives and enable us to eliminate the three unnecessary derivatives (usually those below the main diagonal in J_0) in any particular calculation. On the other hand, in general calculations it is awkward to have to keep inserting this minus sign in front of p whenever it occurs. We may accordingly avoid this trouble by taking a new Jacobian, $J_0' \equiv \partial\,(S, V, L)/\partial\,(T, p, F)$, as our fundamental one. On writing J_0' out we set it equal to a symmetric array of a's (Δ_0 in Eqn. (20)) and then insert *minus* signs according to the two sign rules in Δ_0 only (here in front of the a's in the middle row. which correspond to the p derivatives). Thus we have

$$J_0' \equiv \frac{\partial (S, V, L)}{\partial (T, p, F)} \equiv \begin{vmatrix} \frac{\partial S}{\partial T} & \frac{\partial V}{\partial T} & \frac{\partial L}{\partial T} \\ \frac{\partial S}{\partial p} & \frac{\partial V}{\partial p} & \frac{\partial L}{\partial p} \\ \frac{\partial S}{\partial F} & \frac{\partial V}{\partial F} & \frac{\partial L}{\partial F} \end{vmatrix} = \begin{vmatrix} a_0 & a_1 & a_2 \\ -a_1 & -a_{11} & -a_{12} \\ a_2 & a_{12} & a_{22} \end{vmatrix} \equiv \Delta_0' \qquad (21)$$

In all cases $J_0' = \pm J_0$ (according to the number of sign changes introduced), though the important fact is that *now* Δ_0' is always a symmetric determinant while J_0' may or may not be.

It can now be shown that every derivative made up of primaries only, can be expressed as a ratio of Jacobians which can be read directly out of J_0' (so that tables of evaluated Jacobians need never be prepared unless secondaries are in frequent use). Thus the only Jacobians which can arise are those of the form $(J\,(Y_1, Y_2, Y_3)$, where the Y's are to be selected in all possible ways from the primaries, (T, S, p, V, F, L). But there are only $6.5.4/3! = 20$ essentially different ways of doing this (since we divide by $3!$ to eliminate the result of permuting the order of the Y's). There are thus 20 Jacobians all told; one of those is $J\,(T, P, F)$, (which is unity), 9 are the elements in J_0', 9 are the various minors formed by suppressing a *single* row and column and the last is J_0' itself.

As an example suppose we wish the heat capacity of the system at constant L and V. Since $C_{LV} = T\,(\partial S/\partial T)_{LV}$ we proceed to obtain this derivative. On expanding the derivative into a third order Jacobian and transforming as in Eqn. (10), from (T, V, L) as independent variables to the standard set (T, p, F) we have:

$$\left(\frac{\partial S}{\partial T}\right)_{LV} = \left(\frac{\partial S}{\partial T}\right)_{VL} = \frac{\partial (S, V, L)}{\partial (T, V, L)} = \frac{\dfrac{\partial (S, V, L)}{\partial (T, p, F)}}{\dfrac{\partial (T, V, L)}{\partial (T, p, F)}} = \frac{J_0'}{J'\,(T, V, L)} = \frac{+J_0'}{J'\,(V, L)_T}.$$

But J_0' we have and $J'\,(V, L)_T$ is read from J_0' by suppressing the S-column (since S is not involved) and the T-row (since T is constant). Therefore

$$C_{LV} = C_{VL} = T\,.\,\frac{\begin{vmatrix} a_0 & a_1 & a_2 \\ a_1 & a_{11} & a_{12} \\ a_2 & a_{12} & a_{22} \end{vmatrix}}{\begin{vmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{vmatrix}}$$

where the two minus signs have cancelled.

Again to find the effect on temperature of adiabatic stretching at constant p we want $(\partial T/\partial F)_{pS}$. Proceeding as before

$$\left(\frac{\partial T}{\partial F}\right)_{pS} = \frac{\partial\,(T, p, S)}{\partial\,(F, p, S)} = -\frac{\partial\,(T, p, S)}{\partial\,(p, F, S)} = -\frac{\dfrac{\partial\,(T, p, S)}{\partial\,(T, p, F)}}{\dfrac{\partial\,(p, F, S)}{\partial\,(T, p, F)}} = -\frac{\left(\dfrac{\partial S}{\partial F}\right)_{Tp}}{\left(\dfrac{\partial S}{\partial T}\right)_{pF}}$$

and again reading directly from J_0' in Eqn. (21)

$$\left(\frac{\partial T}{\partial F}\right)_{pS} = -\frac{a_2}{a_0}\text{[11]}.$$

The ease and economy of such deductions are typical of the method and are in marked contrast with deductions by conventional methods, as may be seen by a trial.

If for some reason or other we wish to select another x-set such as say (T, p, L) we have

$$J_0' \equiv \frac{\partial\,(S, V, F)}{\partial\,(T, p, L)} \equiv \begin{vmatrix} \dfrac{\partial S}{\partial T} & \dfrac{\partial V}{\partial T} & \dfrac{\partial F}{\partial T} \\ \dfrac{\partial S}{\partial p} & \dfrac{\partial V}{\partial p} & \dfrac{\partial F}{\partial p} \\ \dfrac{\partial S}{\partial L} & \dfrac{\partial V}{\partial L} & \dfrac{\partial F}{\partial L} \end{vmatrix} \equiv \begin{vmatrix} b_0 & b_1 & b_2 \\ -b_1 & -b_{11} & -b_{12} \\ -b_2 & -b_{12} & -b_{22} \end{vmatrix} \equiv \Delta_0'$$

where b's are used instead of a's since these derivatives are different from those in Eqns. (20) and (21) and the minus sign is inserted in the *middle* row due to the sign of pdV and in the *bottom* row since L was taken out of turn from the term FdL. Use of Eqn. (15) verifies the fact that indeed $\left(\dfrac{\partial V}{\partial T}\right)_{pL} = -\left(\dfrac{\partial S}{\partial p}\right)_{TL}$, $\left(\dfrac{\partial S}{\partial L}\right)_{Tp} = -\left(\dfrac{\partial F}{\partial T}\right)_{pL}$, etc.

[11] This equation then tells us that if F be increased the change in T is opposite in sign to a_2 (since a_0 is surely positive) and therefore normal substances *cool* while materials such as stressed rubber, where $a_2 < 0$, *warm* on stretching.

Again if we chose (T, V, F) we should have:

$$J_0' \equiv \frac{\partial (S, p, L)}{\partial (T, V, F)} \equiv \begin{vmatrix} \frac{\partial S}{\partial T} & \frac{\partial p}{\partial T} & \frac{\partial L}{\partial T} \\ \frac{\partial S}{\partial V} & \frac{\partial p}{\partial V} & \frac{\partial L}{\partial V} \\ \frac{\partial S}{\partial F} & \frac{\partial p}{\partial F} & \frac{\partial L}{\partial F} \end{vmatrix} \equiv \begin{vmatrix} c_0 & c_1 & c_2 \\ c_1 & c_{11} & c_{12} \\ c_2 & c_{12} & c_{22} \end{vmatrix} \equiv \Delta_0'$$

where here both J_0' and Δ_0' are symmetric. The use of such mixed x-sets usually arises in restricted systems where for example F or p may be a function of T only and hence inappropriate in an x-set containing T itself. In this connection it should be emphasized further that systems will arise in practice where only one (usually T) of the primary variables is convenient for inclusion in the x-set. In this case the above arguments based on Eqns. (15) ceases to apply and we must go back to the general Maxwell's Eqns. as given for example in Eqn. (14). It can similarly be seen that Eqn. (14) is still valid even when the expression for dU has not been reduced to the *minimum* number, n, of differential terms. If for example there are n' $(n' > n)$ terms in Eqn. (3) we have n' second order Jacobians in Eqn. (14) and although the result looks cumbersome it is nevertheless more convenient in practice than the usual procedure in which one essentially has to repeat the whole process of Section V in each individual case.

Where secondaries are involved the Jacobians concerned will be more complicated in that derivatives of secondaries with respect to (T, p, F) (or whatever x-set is being used) will appear. These may readily be got from Eqn. (19) and the corresponding forms of Eqns. (4), (5) and (6). "Q" and "W" may be allowed among the secondaries formally since $dQ_c = TdS$ and $dW_c = -pdV + FdL$. We have simply to replace any partial derivative which occurs formally in a Jacobian by its equivalent. Thus for example $\left(\frac{\partial Q}{\partial p}\right)_{TV}$ is interpreted as dQ_{TV}/dp, where this symbol represents the derivative of the heat function at constant T and V and may then be replaced by $T\,(\partial S/\partial p)_{TV}$.

b) $n = 4$ *Single triclinic crystal in an electric field* $(p = 0)$.

Consider a single crystal (of lowest symmetry) in an electric field of components E_1, E_2 and E_3 (these are values of the electric field inside the crystal). Let the corresponding components of the electric induction be D_1, D_2 and D_3. Then the expression for dU, the differ-

ential of the internal energy of the system per *unit volume*, can be written in the form[12]

$$dU = TdS + E_1\,dD_1 + E_2\,dD_2 + E_3\,dD_3 \qquad (22)$$

Strictly speaking we should then divide by the mass density, ρ, and consider $du = 1/\rho\, dU$, where u refers to a fixed mass of unity, as the analogue of Eqn. (3). Actually, since the volume changes due to electrostriction are quite small, Eqn. (22) is adequate. With $n = 4$ the Pfaffian contains $4.5/2 = 10$ terms of which 4 are thermal and 6 isothermal, as the following considerations show.

Since in such a general case the D vector will not be parallel to the E vector, each component of D will have contributions from E_1, E_2 and E_3. Hence

$$\begin{aligned} D_1 &= K_{11}\,E_1 + K_{12}\,E_2 + K_{13}\,E_3 \\ D_2 &= K_{21}\,E_1 + K_{22}\,E_2 + K_{23}\,E_3 \\ D_3 &= K_{31}\,E_1 + K_{32}\,E_2 + K_{33}\,E_3 \end{aligned} \quad . \ . \ . \qquad (23)$$

where the K's are the dielectric constants of the crystal.

On writing J_0 we have

$$J_0 = \frac{\partial\,(S, D_1, D_2, D_3)}{\partial\,(T, E_1, E_2, E_3)} = \begin{vmatrix} \dfrac{\partial S}{\partial T} & \dfrac{\partial D_1}{\partial T} & \dfrac{\partial D_2}{\partial T} & \dfrac{\partial D_3}{\partial T} \\ \dfrac{\partial S}{\partial E_1} & \dfrac{\partial D_1}{\partial E_1} & . & . \\ \dfrac{\partial S}{\partial E_2} & \dfrac{\partial D_1}{\partial E_2} & . & . \\ \dfrac{\partial S}{\partial E_3} & \dfrac{\partial D_1}{\partial E_3} & . & . \end{vmatrix} \quad . \ . \ . \ . \qquad (23A)$$

But the symmetry requirements reduce to $K_{jk} = K_{kj}$ for the K's in Eqn. (23) and we have

$$J_0 = \begin{vmatrix} a_0 & a_1 & a_2 & a_3 \\ a_1 & K_{11} & K_{12} & K_{13} \\ a_2 & K_{12} & K_{22} & K_{23} \\ a_3 & K_{13} & K_{23} & K_{33} \end{vmatrix} \equiv \Delta_0 \quad . \ . \ . \ . \qquad (24)$$

[12] See, for example, JEANS: "Electricity and Magnetism." Cam. Univ. Press, 4th ed., page 152, where a slightly different notation is used. Unless the crystal in this and the examples below belongs to the lowest class of symmetry, the various symmetry demands of the other classes change the system from an unrestricted to a restricted one and therefore modify the treatment considerably.

Here as usual a_0 is a calorimetric coefficient, while $\frac{\partial D_1}{\partial T}, \frac{\partial D_2}{\partial T}$, etc., are *pyro-electric* coefficients, and the isothermal coefficients are simply the 6 independent dielectric constants of the triclinic crystal.

Now it is seen at once that the three pyroelectric coefficients vanish with the field. Thus from Eqn. (23) to (24) we have

$$a_1 = \left(\frac{\partial D_1}{\partial T}\right)_{E_1 \ldots E_3} = \left(\frac{\partial K_{11}}{\partial T}\right)E_1 + \left(\frac{\partial K_{12}}{\partial T}\right)E_2 + \left(\frac{\partial K_{13}}{\partial T}\right)E_3 = \left(\frac{\partial S}{\partial E_1}\right)_{TE_2E_3}$$

and hence there is *no* pyroelectric effect unless there is a *field* present. Hence no pyroelectric effect in the usual sense of the word is present unless we have *added* to each of the right sides of Eqns. (23) terms D_{10}, D_{20} and D_{30}, respectively, where these quantities represent *permanent* electric moments (being functions of temperature in this case—but of stress as well in the general case). These permanent states of polarization are then the origins of true pyroelectricity and can be expected only for crystals having a onewayness in some direction, i. e., at least *one* polar axis due to the physical asymmetry of the crystal class. This is of course well known, but the above analysis gives the fundamental thermodynamic requirements in a very direct way.

c) $n = 7$ *Triclinic crystal under small homogeneous strain*

If we now imagine our single crystal to be subject to a general stress it can be shown[13] that Eqn. (3) for a unit volume becomes

$$dU = TdS + \sum_{i=1}^{6} F_i \, d\theta_i \tag{25}$$

where $(F_1 \ldots F_6)$ are the usual components of stress $(X_x, X_y, Y_z, Z_z, X_y)$ while $(\theta_1 \ldots \theta_6)$ are the corresponding strain components $(e_{xx}, e_{yy}, e_{zz}, e_{yz}, e_{zx}$ and $e_{xy})$.

In this case the generalized Hooke's law enables us to express the θ's directly in terms of the F's. We have in fact 6 equations (analogous to the 4 in Eqns. (23)) expressing each θ as a linear function of the F's. Thus

[13] See A. E. H. Love, Mathematical Theory of Elasticity. Camb. U. Press, 4th ed., 1934, page 94.

$$\begin{aligned}\theta_1 &= \theta_{10} + C_{11} F_1 + C_{12} F_2 + C_{13} F_3 + C_{14} F_4 + C_{15} F_5 + C_{16} F_6 \\ \theta_2 &= \theta_{20} + C_{21} F_1 + C_{22} F_2 + C_{23} F_3 + C_{24} F_4 + C_{25} F_5 + C_{26} F_6, \text{ etc.}\end{aligned} \tag{26}$$

where θ_{10}, θ_{20}, etc., are functions of temperature only. These involve 36 general elastic constants $C_{11} \ldots C_{66}$. Just as before we set up J_0 which is a square array of $7^2 = 49$ terms consisting of a smaller square of 36 *isothermal* constants bordered by a row and column of 13 thermal and entropy constants. By the symmetry requirements these reduce to $7.8/2 = 28$ independent terms, 7 thermal and $6.7/2 = 21$ isothermal. Thus putting $C_{jk} = C_{kj}$, etc., we have

$$J_0 = \frac{\partial\,(S, \theta_1 \ldots \theta_6)}{\partial\,(T, F_1 \ldots F_6)} = \begin{vmatrix} a_0 & a_1 & a_2 & \cdot & \cdot & \cdot & a_6 \\ a_1 & C_{11} & C_{12} & \cdot & \cdot & \cdot & C_{16} \\ a_2 & C_{12} & C_{22} & \cdot & \cdot & \cdot & C_{26} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ a_6 & \cdot & \cdot & \cdot & \cdot & \cdot & C_{66} \end{vmatrix} \tag{27}$$

As before we are now in a position to determine in terms of these 28 coefficients any new derivative. As an example consider any dynamically determined elastic constant where the deformations are so rapid that we may assume them *adiabatic*, such as $(\partial\theta_2/\partial F_2)_{SF_1F_3 \ldots F_6}$. Then

$$\left(\frac{\partial\theta_2}{\partial F_2}\right)_{S\,F_1\,F_3 \ldots F_6} = \frac{\partial\,(\theta_2, S, F_1, F_3 \ldots F_6)}{\partial\,(F_2, S, F_1, F_3 \ldots F_6)} = -\frac{\partial\,(S, \theta_2, F_1, F_3 \ldots F_6)}{\partial\,(S, F_1, F_2, F_3 \ldots F_6)}$$

$$= \frac{\dfrac{\partial\,(S, \theta_2, F_1, F_3 \ldots F_6)}{\partial\,(T, F_2, F_1, F_3 \ldots F_6)}}{\dfrac{\partial\,(S, F_1, F_2 \ldots F_6)}{\partial\,(T, F_1, F_2 \ldots F_6)}} = \frac{J(S, \theta_2)_{F_1\,F_3 \ldots F_6}}{\left(\dfrac{\partial S}{\partial T}\right)_{F_1 \ldots F_6}} = \frac{\begin{vmatrix} a_0 & a_2 \\ a_2 & C_{22} \end{vmatrix}}{a_0}$$

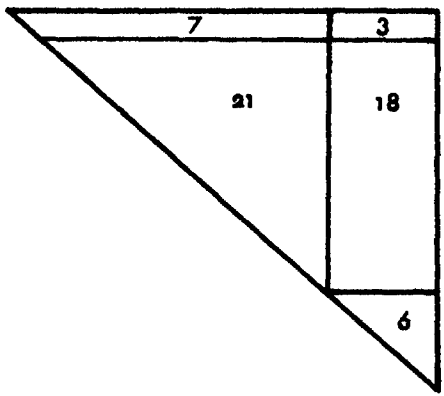
where a number of short cuts suggest themselves automatically in practice.

d) $n = 10$ *General Piezo electric crystal*

It is apparent without further repetition of similar details that we have the material at hand for a complete formal discussion of the general piezo electric crystal, i. e., of the triclinic crystal under general mechanical stress and arbitrary electric field. If we add to TdS the non-thermal parts of Eqns. (22) and (25) we have for a unit volume

$$dU = TdS + \sum_{i=1}^{6} F_i\, d\theta_i + \sum_{i=1}^{3} E_i\, dD_i \tag{28}$$

Since n is now 10 the Pfaffian contains $10.11/2 = 55$ coefficients and without writing them out in detail their general nature becomes clear from the block diagram of the 10th order Pfaffian. On the top row



we have a_0 and 6 *dilations* from Eqn. (27) and the 3 *pyro-electric* coefficients from Eqn. (23A). Below are triangular blocks of the 21 isothermal elastic constants and 6 dielectric constants from the same equations and finally a rectangular block of 18 *new* coefficients the *piezo-electric* constants proper. These latter result from the interaction of the stress and the field and bring the total to the number required by our theory, viz., 55.[14]

[14] See for example W. G. Cady: "Piezoelectricity." McGraw-Hill, 1946, p. 44, where essentially the same group of constants is given (in quite a different notation) in their relation to a closed expression for A, the work function.

Proceedings of the American Academy of Arts and Sciences

Vol. 78, No. 4, P. 185 219—August, 1950

THE LOWER PERMIAN INSECTS OF KANSAS

Part 10. The Order Protorthoptera: The Family Liomopteridae and Its Relatives

By Frank M. Carpenter

THE LOWER PERMIAN INSECTS OF KANSAS

Part 10. The Order Protorthoptera: The Family Liomopteridae and Its Relatives*

By Frank M. Carpenter

An introduction to this study of the Protorthoptera and a discussion of the unusual problems involved were contained in the previous paper of this series (1943). Included also was an account of one of the protorthopterous families, the Probnisidae, as it occurs in the Elmo limestone. The present paper deals with six more families. All of these appear to belong to one phylogenetic complex of the order and also to be close relatives of the Lemmatophoridae, which constitute the extinct order Protoperlaria.

The specimens which form the basis of this study are in the collections of the Museum of Comparative Zoology at Harvard University and the Peabody Museum at Yale University. This series of fossils contributes significantly to our knowledge of the Protorthoptera. As I have previously indicated (1943), the confused state of our knowledge of the Protorthoptera is due in large part to the scant information we have of them. The genus *Probnis*, considered in the previous paper, is the only member of the order of which we have a working knowledge of all four wings and body. Fortunately, the excellent material available for the present study provides us with comparable knowledge of several other genera. A discussion of their relationships and those of other, less satisfactorily known genera will follow the descriptive account of the fossils. Wherever possible, I have included a restoration of each species, based on all material at hand. Such composite figures show only parts actually seen in the specimens, unless otherwise indicated.

The ten species treated here belong to eight genera and six families. Since most of the genera are monotypic, distinctions between specific, generic, and family traits are essentially arbitrary and will probably need to be modified as other species become known.

Family Liomopteridae

This family was erected by Sellards in 1909 for three species in the Elmo limestone. Two of these (*ornatum* and *extensum*) were placed in *Liomopterum* Sellards, and the third (*elongatum*) in a separate genus,

* This investigation has been aided by a grant from the Milton Fund of Harvard University.

Horates. In the new material from the Elmo limestone there are specimens of three additional species, one being a *Liomopterum*, the others representing two new genera. The importance of this new material, however, lies in the information which it gives of the detailed structure of the body and hind wing of the commonest species of the family, *L. ornatum*. Unfortunately, almost nothing is known of the hind wings or of the body structure of the other species found. It is consequently impossible to indicate family characteristics involving these parts of the insects except on the assumption that other species of the family share them with *ornatum*. I have therefore assigned these species to the Liomopteridae largely because of the structure of the fore wing. Additional material, giving information of other parts of the insects, may of course show that separation of some species into distinct families is necessary.

That the family Liomopteridae has representatives in other Permian deposits is most probable. One such species has been placed there by Martynov—*Haplopterum majus* from the Russian Permian—but since it is known only from the remigium of a hind wing, its position in the Protorthoptera is uncertain. However, *Kazanella rotundipennis* and *K. compressa*, which Martynov also described (1930) from the Russian Permian and placed in the Protoperlaria (Lemmatophoridae), probably belong to the Liomopteridae. Only fragments of the fore wings are known, but their preserved parts are highly suggestive of the corresponding portions of *Liomopterum*.

As far as known, the Liomopterids were small to medium in size, the largest having a wing expanse of about 65 mm. The fore wings were membranous and were at least partially covered with short but conspicuous hairs. The subcosta terminated on the costa, about two-thirds the wing-length from the base, and the costal area contained numerous cross-veins, nearly uniformly slanted and with very little branching and cell formation. The radius extended well to the apex of the wing and its sector (Rs), arising before mid-wing, had at least two terminal branches. The media was forked at about the level of the origin of Rs (or slightly basal), forming a main anterior branch (MA), usually with several terminal branches, and a main posterior branch (MP), usually forked. MA and MP were not anastomosed with other veins. The cubitus (Cu) was formed as characteristic of this whole group of protorthopterous families, with the anterior cubitus (CuA) arising basally, diverging anteriorly, and then forking into two main branches; the outer (CuA1) had at least two terminal branches, but the inner was always unbranched. The wide space between CuA and CuP contained at most a double row of cells. The posterior cubitus (CuP), apparently as in all the Protorthoptera, was

unbranched. The first anal (1A) was also unbranched but 2A was at least forked. Cross-veins were numerous in the wing, and in some species formed a coarse reticulation, but not with more than two rows of cells between veins.

The hind wing, which is known only in *Liomopterum ornatum*, had a narrower costal space than the fore wing, and Rs arose nearer the base; M and CuA were fused to form a single stem; CuA was a strong vein, deeply forked; CuP was very weak; 1A was close to CuP and straight; 2A was forked. The anal area was well developed, with many radial veins.

The body structure is known in *Limopterum* and *Semopterum*, n. gen., but all members of the family probably had the same general features. The antennae were multisegmented and fully as long as the body of the insect; the head was hypognathous and the eyes prominent; the prothorax had conspicuous lateral expansions, apparently membranous, but completely surrounding the pronotum itself; the cerci were long, and the legs slender, the hind legs being much longer than the others though not modified for jumping; the tarsi were 5-segmented.

The three genera which represent this family in the Elmo limestone differ in venational features of the fore wings, the relative position of the origins of Rs, MP, and CuA2, and the general pattern of the cross-veins.

Genus *Liomopterum* Sellards

Liomopterum Sellards, 1909, Amer. Journ. Sci., (4) **27**: 157
Horates Sellards, 1909, ibid., 158

Fore wing: costal area moderately broad, the costal margin convex; main fork of M proximal to origin of Rs; cross-veins moderately numerous, with cellules (when present) almost exclusively confined to the area between CuA and CuP.

The hind wing, which is known only in *ornatum*, is described below under that species. The cerci were as long as the abdomen; the hind legs were about three times as long as the fore pair; the first and fifth tarsal segments were subequal, the third and fourth very short, and the second slightly longer.

Genotype: *Liomopterum ornatum* Sellards

Liomopterum ornatum Sellards

Figure 1; figure 2A; plate 1, figure 1.

Liomopterum ornatum Sellards, 1909, Amer. Journ. Sci., (4) **27**: 158, figs. 5, 6.
Liomopterum extensum Sellards, 1909, ibid., 158

Fore wing: length, 13–15 mm.; width, 4–6 mm. Costal margin strongly convex; costal veinlets well developed and varying from 13 to 20, mostly unbranched, and rarely sigmoidal; Rs usually with three terminal branches, R2, R3, R4 + 5; MA and MP usually with two terminal branches; CuA forking slightly proximal to the fork of M,

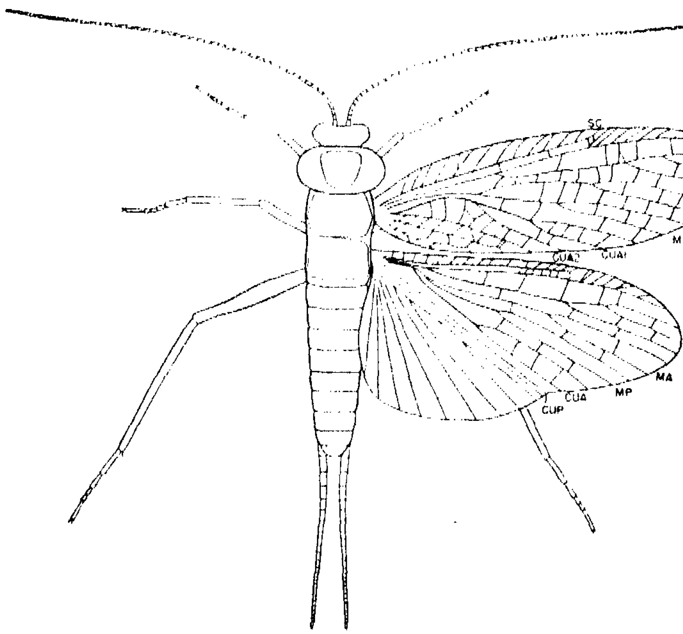


FIGURE 1. *Liomopterum ornatum* Sellards. Restoration based on specimens in the Harvard and Yale collections. Sc, subcosta; R1, radius; Rs, radial sector; MA, anterior media; MP, posterior media; CuA, anterior cubitus; CuP, posterior cubitus; 1A, first anal vein.

and usually with three terminal branches, CuA1a, CuA1b, and CuA2. 1A curved away from CuP near its middle; 2A also curved, submarginal distally; a small remnant of 3A is usually present. Cross-veins mostly straight, with sigmoidally shaped ones usually present between CuA and CuP, but with no regularly differentiated series. Well preserved specimens show three pigment spots, as can be seen in the photograph (plate 1, fig. 1); one spot near mid-wing, another at the separation of CuA2 from CuA1, and the third—a more diffuse area—around the branches of Rs, where the cross-veins are usually margined. The wings have a dense covering of short hairs, clearly preserved in good specimens.

Hind wing: length, 13–14 mm.; maximum width, 5.6 mm. Costal margin slightly concave; M with three or four branches; MA and MP separating below the origin of Rs; MA and MP forked, the latter more deeply. There are no indications of color markings but many hairs like those on the fore wing are discernible.

Body structure: length of body, 13 mm. The head is 3 mm. wide across the eyes, and about as long; the prothorax, 1.5 mm. long and 3.3 mm. wide across the lateral lobes; mesothorax, 2.1 mm. long and 2.4 wide; metathorax, 1.9 mm. long, and 2.2 mm. wide; whole abdomen, 6.4 mm. long; cerci, 6.5 mm. long; fore femur, 2 mm. long (beyond body), tibia, 1.5 mm. long, tarsus, 2.2 mm. long; middle femur, 2.4 mm. long, tibia, 2.7 mm. long, tarsus, 2.2 mm. long; hind femur, 4 mm. long, tibia, 5.5 mm. long, tarsus, 3 mm. long.

The original type of *ornatum* was specimen no. 5 in the Sellards collection, but since that has been lost, I designate as the neotype specimen no. 4828, Museum of Comparative Zoology, collected at the Elmo locality in 1927. This consists of a complete fore wing (see plate 1, figure 1).

This is one of the common insects in the Elmo limestone fauna. It is represented in the Yale collection by 12 specimens and in the Harvard collection by 73 specimens, of which 36 are from the lower layer of the limestone. Most of these consist of fore wings, of which the following are especially well preserved: M. C. Z. 4827, 4828, 4829, 4830, 4831, 4838, 4840; P. M. 15619, 15746. The hind wing is well shown in specimens nos. M. C. Z. 4842, 4843, 4844; and the body structure in nos. M. C. Z. 4833, 4834, 4855, 4876, 4878; P. M. 15608, 15609.

The wing venation of *ornatum*, as might be expected, is highly variable. A comparison of the fore wings of the extensive series of specimens at hand shows that the usual or normal condition, present in about 90% of the individuals, is as follows: R2, R3, R4 + 5, MA1, MA2, MP1, MP2, CuA1a, CuA1b, CuA2. In about 7% of the specimens, however, R2 is twigged or shallowly forked; in one specimen (P. M. 15742), CuA2 is forked, CuA1 being unbranched; and in two specimens CuA1 is unbranched. The cross-veins show the usual amount of variation; in the area between CuA and CuP a few cells may be found in some specimens, but in others there are only sigmoidal cross-veins. The hind-wing venation appears to be less variable, but of course there are fewer specimens for comparison.

I believe the synonymy of *extensum* with *ornatum* to be unquestionable. Both of these species were based on single specimens, which I studied and photographed. The type of *ornatum* had the usual venation mentioned above, except that MP was unbranched.

The type of *extensum* was separated by Sellards from *ornatum* because MP was forked and CuA unbranched, but, as indicated above, these differences fall well within the fluctuations which occur in this species.

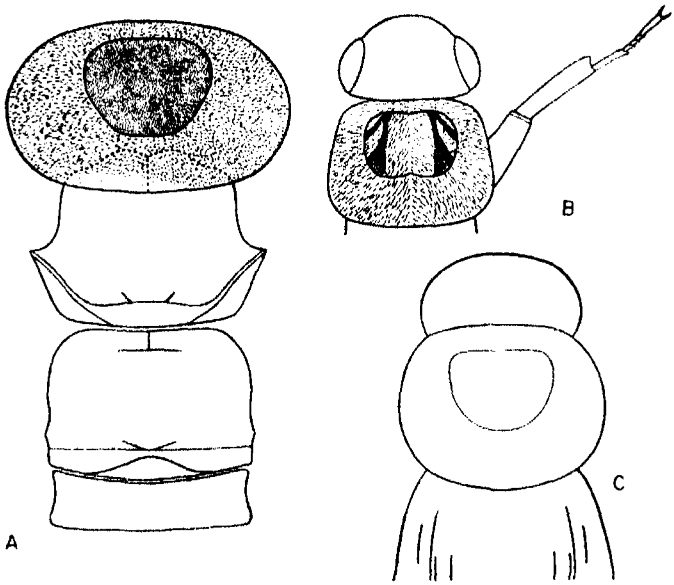


FIGURE 2. Liomopteridae. A, restoration of thorax of *L. ornatum* from above, showing the hairs on the prothoracic marginal area, around the pronotum proper; based on specimens M. C. Z. 4834 and P. M. 15621. B, Head, pronotal area and fore leg of *Tapopterum celsum*, n. sp., showing hairs covering pronotal area; based on specimen M. C. Z. 4941. C, outline of head, pronotal area and wing bases of *L. sellardsi*, dorsal view; based on specimen M. C. Z. 4936.

Liomopterum elongatum Sellards

Figure 3; plate 1, figure 2.

Horates elongatus Sellards, 1909, Amer. Journ. Sci., (4) **27**: 158, fig. 2.

Fore wing: length, 18–21 mm.; width, 6–7 mm.; shape much as in *ornatum*, but with apex more pointed. Costal area about as broad as in *ornatum;* Rs with two or three terminal branches; M forking into MA and MP proximad to the origin of Rs; MA with three or four terminal branches, MP with two; CuA shaped much as in *ornatum;* CuA1 and CuA2 usually separating at about the level of separation of MA and MP, more rarely at a more distal position. CuP and the anal veins much as in *ornatum*. Cross-veins somewhat more numerous

than in *ornatum*, but there are more cells between CuA and CuP, and there is a tendency for cell formation between Rs and R1.

Hind wing: only the proximal half of the remigium is known; this shows a venational pattern like that of *ornatum* except that MA arises nearer the base of the wing (i. e., just proximad to origin of Rs) and MA is forked to about the same level as MP.

Body structure: length of body, 16 mm. Few details are known, but the head appears to be like that of *ornatum*, with prominent eyes. The thoracic segments are each about 2 mm. long, and the abdomen is 8 mm. long; the cerci are only incompletely known, although one of

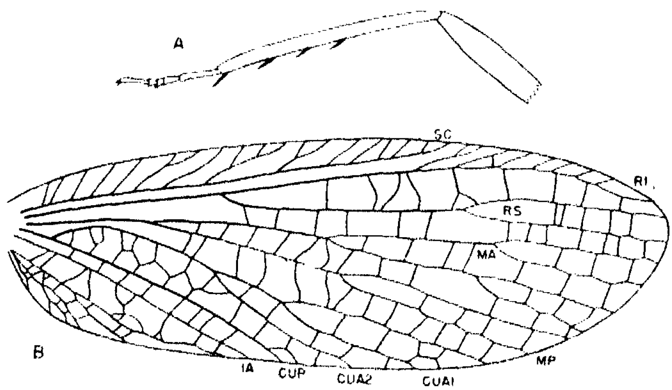


FIGURE 3. *Liomopterum elongatum* (Sellards). A, hind leg (femur incomplete) of specimen M. C. Z. 4962. B, fore wing of neotype, lettering as in figure 1.

them is 5 mm. long to the point where it is broken; the hind leg as preserved is 20 mm. long, the femur being 4.5 mm. long (incomplete), the tibia, 8 mm., and the tarsus 3.5 mm. The tarsal segmentation is like that of *ornatum*, the first segment being the longest, the third and fourth very short. The femur is not nearly so broad as that of *ornatum*, and the tibia has several prominent spines along the ventral surface. Nothing is known of the structure of the other legs or of the antennae and pronotum.

Type: The type of *elongatum* was specimen no. 992, Sellards collection; this being lost, I designate as the neotype specimen no. 15012ab, in the Peabody Museum, Yale University. This is a complete and well preserved fore wing, collected at the Elmo locality by C. O. Dunbar.

This is not a common species in the Elmo deposit, there being but six specimens in both the Harvard and Yale collections, nos. M. C.

Z. 4889, 4928, 4962, P. M. 15749, 15573. Two of the three Harvard specimens are from the upper layer of the limestone.

Only one of the six fossils, no. 4962, shows any of the body. This specimen, which also includes a fore wing and part of a hind wing, shows the general body form; one metathoracic leg is very well preserved (figure 3). The femur is not so broad as that of *ornatum*, but in other respects the hind legs of the two insects are nearly identical.

I have identified the above specimens as *elongatum* on the basis of Sellards' figure and description; the type could not be found in his collection when I examined it at Austin, Texas, in 1927. Sellards' drawing shows that the type was fragmentary, consisting of only the proximal third of a fore wing. However, there is enough of the venation preserved to justify the assignment of these specimens to *elongatum*.

As I have indicated above a new genus scarcely seems necessary for *elongatum*. Since Sellards did not separate his generic and specific diagnoses, it is not possible to analyze his definition; but I can see no reason for retaining the generic distinction.

Liomopterum sellardsi, n. sp.

Figure 2C; figure 4.

Fore wing: length, 17–18 mm.; width, 6.2–6.5 mm. Costal margin curved as in *elongatum*, but the apex of the wing is more tapering. Proximal part of Sc closer to the margin than the distal part, the curve of Sc being proximal to the origin of Rs. Rs with two or three terminal branches. M forked just before the origin of Rs; MA with four or five terminal branches; MP forked; CuA like that of *elongatum*, except that CuA2 arises nearer the base; cross-veins about as numerous as in *ornatum*, the distal ones being very weak; cellules occur in the area between CuA and CuP, CuA1 and CuA2, and MP and CuA1.

The hind wing is unknown, but some of the body structures are preserved in one specimen (4936). The head is 3.7 mm. wide at the level of the eyes. The prothorax has a dorsal shield, 5 mm. wide, which consists of a distinct pronotum and the extended lobes, as in *ornatum*. The entire shield, however, is more nearly circular than that of *ornatum*. One hind leg is preserved in dorsal view (except for the tarsus), with the following dimensions: coxa, 1.5 mm. long; trochanter, 1 mm.; femur, 4.5 mm.; tibia, 8 mm.; tarsus (incomplete), 2.5 mm. The combined lengths of the femur, tibia and tarsus total 15 mm., which indicates that the hind legs of *sellardsi* were relatively the same size as those of *ornatum*.

Holotype: No. 4978, Museum of Comparative Zoology; collected at the Elmo locality by F. M. Carpenter. This consists of a complete fore wing, 18 mm. long and 6.5 mm. wide.

Paratypes: M. C. Z.: No. 4937, a nearly complete fore wing; No. 4939, an incomplete insect, showing part of fore wing and prothorax; No. 4940, an incomplete insect, showing fore wing, part of the body and a hind leg. Peabody Museum: No. 16180, a complete fore wing,

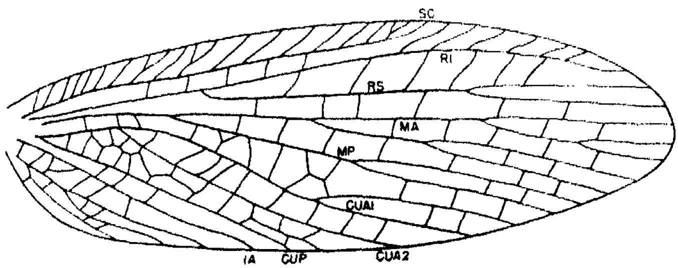


FIGURE 4. *Liomopterum sellardsi*, n. sp. Fore wing, drawn from holotype. Lettering as in figure 1.

well preserved. In addition to the types listed, there are two poorer specimens in the Harvard collection, nos. 4935 and 4933. All specimens of this species were collected in the lower layer of the limestone.

This species, which is about the size of *Liomopterum elongatum*, differs in the shape of the wing, and by having a distinct proximal bend in the subcosta. The latter feature is constant in all specimens at hand.

Tapopterum, new genus

Fore wing: costal area narrow, the costal margin straight or nearly so at the middle; main fork of M proximal to origin of Rs; CuA forking proximad of first fork of M; cross-veins numerous, with at least a few cellules present between most main veins.

Hind wing unknown. The body structure, so far as known, resembles that of *ornatum*.

Genotype: *Tapopterum celsum*, n. sp.

Tapopterum celsum, n. sp.

Figure 2B; figure 5; plate 2, figure 1.

Fore wing: length, 19 mm.; width, 6 mm.; widest beyond the center of wing; costal space slightly narrower in the proximal third of wing than beyond; Rs forking into R2 + 3 and R4 + 5 just beyond mid-wing; R2 with four terminal branches; R3, R4, and R5 unbranched; MA and MP forked to about equal depth; CuA1 forked, somewhat more deeply than MP; CuA2 unbranched; 1A unbranched; 2A forked. Cross-veins numerous with differentiation over various areas of wing.

In the subcostal area, basal to the origin of Rs, there are five veins, forming cellules; further distally, the cross-veins are stronger, long, and sigmoidal; no cellules in distal part of wing; two rows of cellules between the proximal parts of MA and MP, MP and CuA, CuA and CuP.

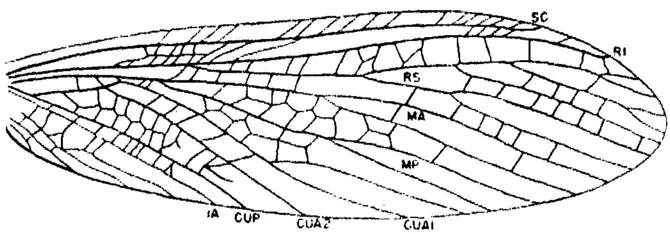


FIGURE 5. *Tapopterum celsum*, n. sp. Drawing of fore wing, based on holotype. Lettering as in figure 1.

Most of the wing except the distal part has prominent maculations, the spots being located in the cellules, as shown in plate 2, figure 1. The wing is also covered with fine, short hairs, much shorter than those of *Liomopterum ornatum*.

Hind wing unknown.

Nothing is known of the body structure except for the head, prothorax, and fore leg, which are preserved in specimen no. 4941. The head, seen in dorsal view, is 2.3 mm. at the level of the eyes; the prothoracic disc is differently shaped from that of *Liomopterum*, its lateral margins being nearly straight, instead of curved. The pronotum itself shows a distinct color pattern, symmetrical on the two sides of the plate. The fore leg is relatively shorter and stouter than that of *Liomopterum*, the femur being 2.3 mm. long beyond the body; the tibia and tarsus each 2 mm. long. The tarsus is 5-segmented, with the segments much like those of *Liomopterum*.

Holotype: No. 4930, Museum of Comparative Zoology. Collected at the Elmo locality by F. M. Carpenter. This consists of a complete and well preserved fore wing.

Paratype: No. 4941ab, M. C. Z., consisting of part of a whole insect, but with metathorax and abdomen distorted or broken away.

This species seems unquestionably related to the genus *Liomopterum*, but the narrow costal area, larger number of cellules, and the more extensive development of the radial sector make it generically distinct.

Semopterum, new genus

Fore wing: costal area moderately broad, the margin strongly curved; main fork of M at about the level of origin of Rs or slightly basal to that part; CuA forking proximally to first fork of M; cross-veins more numerous than in *Liomopterum* and *Tapopterum;* costal veinlets with few or no branches; cellules very few and confined to proximal half of wing.

Hind wing unknown.

Genotype: *Semopterum venosum*, n. sp.

Semopterum venosum, n. sp.

Figure 6.

Fore wing: length, 29 mm.; width, 9 mm.; Rs with from three to five terminal branches; MA with from three to five terminal branches; MP with two terminal branches; CuA forking proximad to origin of Rs; CuA1 with three terminal branches, all distal to the axis of CuA1;

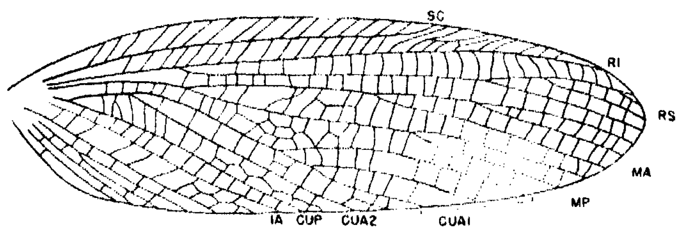


FIGURE 6. *Semopterum venosum*, n. sp. Drawing of fore wing, based on holotype. Lettering as in figure 1.

CuA2 unbranched; anal angle of wing conspicuously developed with 3A and 4A separate and distinct. The cross-veins between R1 and Rs are uniformly curved, as far distal as the origin of R4 + 5; beyond that point they are sigmoidal.

The wing was probably heavier and thicker than that of *Liomopterum* or *Tapopterum*. A few scattered patches of hairs are preserved in one specimen (P. M. 15750), and the holotype has small irregular blotches of reddish brown.

Hind wing and body structure unknown.

Holotype: No. 4924, Museum of Comparative Zoology; collected at the Elmo locality by F. M. Carpenter. This is a well preserved fore wing, complete except for a small piece of the hind margin.

Paratypes: No. 4953, Museum of Comparative Zoology, the distal half of a fore wing. No. 15750, Peabody Museum, a well preserved fore wing, lacking the posterior margin and apex. No. 15635ab,

Peabody Museum, a well preserved fore wing, lacking the proximal fourth.

In addition, there are two fragments of fore wings in the Harvard collection. All specimens, except one of the latter, are from the lower layer of the limestone.

This species, which apparently had a wing expanse of about 27.5 mm. (3 inches), differs from the other Liomopterids in several obvious respects. The cross-veins are more numerous, the area between CuA and CuP is no greater than that between other veins, and the anal veins are better developed. The last-mentioned characteristic is the most interesting, since it reflects the condition found in other families, described below.

CHELOPTERIDAE, new family

Insects of medium size, related to the Liomopteridae. The fore wing was membranous, but lacked hairs. The subcosta terminated on the costa about two-thirds the wing length from the base, as in the Liomopterids, but it seemed to terminate sooner because of ite abrupt approach to the costal margin. The costal area had numerous cross-veins slanted at various angles and many of them were forked. The radius extending nearly to the apex, its sector arising not far from mid-wing, with at least two branches. The anterior (MA) and posterior (MP) branches of M had several forks. The cubitus was essentially as in the Liomopteridae, with CuA diverging anteriorly at the base of the wing and dividing into two main branches (CuA1, CuA2). 1A was either unbranched or forked and 2A branched. Cross-veins were numerous, strong basally but weak distally; cellules were very few and the cross-veins between Rs and R1 were slanted and nearly parallel.

The hind wing had a general form like that of *Liomopterum*. Rs arose even nearer the base of the wing than in the latter, however; the stems of R, M, and Cu were apparently coalesced; and CuA was unbranched. The anal area was somewhat larger than that of *Liomopterum*, and had more radiating veins. Cross-veins formed a distinct network of cells in various parts of remigium.

The body structure is unusually well known. The antennae were almost as long as the wing, but had only about half as many segments as in the Liomopteridae. The head was broad, with conspicuous eyes. The prothorax possessed a dorsal disc consisting of the pronotum and a flat marginal area, apparently membranous, but lacking the hairs found in the Liomopteridae. The cerci of the male were modified to form forceps; the female had a prominent, exserted ovipositor. The hind legs were not much longer than the middle pair, and all tarsi were 5-segmented.

Chelopterum, new genus

Fore wing: costal area broad proximally, abruptly narrowed at about mid-wing; origin of Rs slightly proximal to mid-wing, and main fork of M just proximal to origin of Rs; CuA1 and CuA2 separating before main fork of M; cross-veins between CuA and CuP usually form a few large cells.

Hind wing: as characterized in the account of the family; network of cross-veins occurring in the distal part of the wing between each branch of a vein; and also between CuA and MP.

The body structure will be described below under the account of the species.

Genotype: *Chelopterum peregrinum*, n. sp.

Chelopterum peregrinum, n. sp.

Figure 7; plate 3, figures 1 and 2.

Fore wing: 14–17 mm. long, 4–5.5 mm. wide. Costal margin slightly curved, apex broadly rounded; costal veinlets from 20 to 30 in number, varying in slant and shape; cross-veins between R1 and Sc

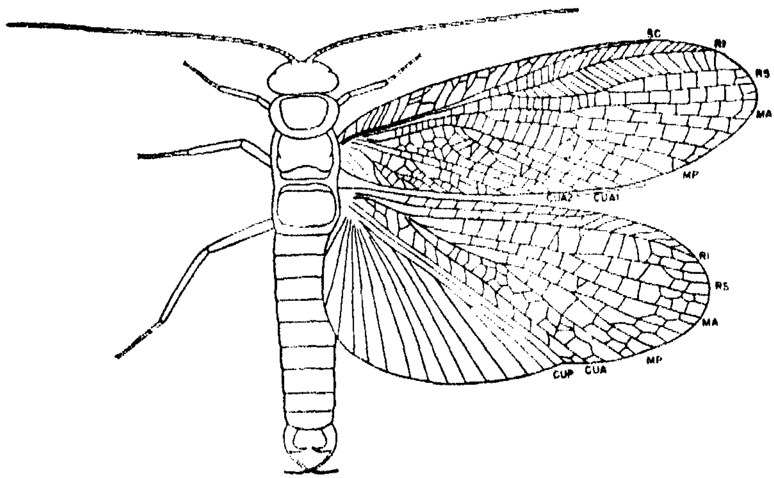


FIGURE 7. *Chelopterum peregrinum*, n. sp. (Male). Restoration based on specimens in Harvard and Yale collections. Lettering as in figure 1.

slanted in opposite direction from those between R1 and Rs; Rs with two branches in most specimens (85%), less often with three branches; MA with two branches in most specimens (80%), less often (15%) with three branches, and rarely (5%) with four branches; MP with either four branches (55%) or three branches (40%), rarely with two

branches (5%); CuA1 highly variable, with from two terminal branches to five long branches. The cross-veins are strong in the proximal part of the wing, but almost completely absent distally; a faint trace of reticulation is discernible in the apical region. Many specimens of fore wings show distinct markings; these consist of two dark transverse bands, usually reddish as preserved, one across the pterostigmal area, the other just proximal to mid-wing.

Hind wing: length, 11–12 mm.; maximum width, 5–6 mm.; Rs deeply forked, MA unbranched, MP with three terminal branches; 2A with five or six terminal branches; at least seven additional, radiating anal veins.

Body structure: length of body, 11 mm. The head, shown best in specimen M. C. Z. 4896, is about twice as wide as it is long, when seen from above. The eyes are conspicuous. The antennae, which are preserved in specimen M. C. Z. 4905, are about two-thirds as long as the fore wing, and include about twenty-one segments, the proximal ones being much shorter than those in the distal part. The pronotum, which is clearly preserved in specimens M. C. Z. 4905 and P. M. 15745, is encircled by the flat, lateral expansions, the margin being narrowest anteriorly. This marginal area is apparently much thinner than the central pronotal plate, and was probably membranous, though hairs are not visible. The mesonotum is large and shows a weakly defined scutellum. Although the legs are incompletely known, the fore legs are apparently much shorter than the others. The mesotarsal segmentation only is known (M. C. Z. 4897); the first two segments are subequal, the next two very short, and the fifth, about as long as the first. The hind legs are much longer than the middle pair, though not nearly so long as in *Liomopterum*. Nine segments of the abdomen can be seen in several specimens, though in most some distortion has resulted from flattening. The remaining two segemnts are presumably reduced and modified as to be indistinguishable from above. Several specimens show distinct terminal processes in the form of curved forceps, with a slender curved filament attached to each. Since such specimens show no indications of typical cerci, I infer that these structures are modified cerci and that individuals possessing them are males. Other specimens, however, possess short but normal cerci, in addition to a medial process, obviously an ovipositor, which is about two-thirds as long as the abdomen.

The following are dimensions of the specified body structures: head, 1 mm. long (seen from above), 2.2 mm. wide; antennae, 9 mm. long; prothorax, 2 mm. long, 2.5 mm. wide; mesothorax, 2.5 mm. long, 2 mm. wide; metathorax, the same; abdomen, 6 mm. long, 2.2 mm. wide (maximum); cerci male, 1.5 mm. long; female, 1 mm. (incomplete);

fore tibia, 1.5 mm. long, fore tarsus, 1.2 mm. long; mesothoracic tibia and tarsus, each 1.5 mm. long; hind femur 2.5 mm. long (incomplete); hind tibia, 2.5 mm. long. Ovipositor, 5 mm. beyond abdomen.

Holotype: No. 4904, Museum of Comparative Zoology; collected by F. M. Carpenter at the Elmo locality. This consists of a nearly complete specimen, showing fore and hind wings and much of the body.

Paratypes: In the Museum of Comparative Zoology: nos. 4891, 4892, 4906, all fore wings; nos. 4897, 4898, 4901, 4903, all showing the wings and body; nos. 4902 and 4910, hind wings. In the Peabody Museum: nos. 15443, 15645, 15658, 15739, 15443, all fore wings; no. 15745, consisting of the wings and body.

This is not a rare insect in the Elmo limestone. In the Peabody Museum collection there are thirteen specimens and in the Museum of Comparative Zoology, forty-five specimens (with equal representation of the two layers), making a total of seventy-three. Although certain details are lacking, our knowledge of the structure of this insect surpasses that of nearly all other Protorthoptera. The most notable feature is the modified cerci of the males. There is no doubt that both the stout hooks and the slender distal processes are part of the same structure. In all seven specimens showing the cerci, the relative position of the hooks and distal processes is identical—a condition which would scarcely exist, if the two were independent. The distal filaments, though showing no indications of segmentation, are perhaps the apical parts of the cerci, the stout hooks being formed by the proximal portion. Cheliform cerci are not uncommon among true Orthoptera, especially the Tettigoniidae, and some are toothed, but none, so far as I am aware, are quite like those of *Chelopterum*.

The presence of the ovipositor is another interesting feature of this insect. Unfortunately, since both specimens which show the ovipositor are preserved in a dorso-ventral position, its shape cannot be accurately determined. However, as seen in these fossils, it is very straight and slender, looking much like the ovipositor of the Gryllidae.

STEREOPTERIDAE, new family

Small insects, apparently related to the Liomopteridae. The fore wing was somewhat coriaceous, with a few patches of conspicuous hairs, but without a complete covering of microtrichia. Sc terminated about two-thirds the wing length from the base; the costal area contained many cross-veins slanted at various angles, but rarely forked. The radius terminated before the apex of the wing, its sector arising before mid-wing; MA and MP were unbranched or forked; the cubitus was formed as in the Liomopterids except that CuA, after leaving CuP, coalesced for a short distance with M before curving

posteriorly again; 1A was unbranched and the other anal veins were crowded and reticulate. The cross-veins were numerous over the wing, those between R and Sc being long and sigmoidal. A coarse net-work of cross-veins occurred between CuA and CuP.

The hind wing and body structure are unknown.

Stereopterum, new genus

Fore wing: costal area nearly uniform for most of its length; MA and MP separating about at the level of origin of Rs; MA terminating at wing apex; other characteristics as given under the species.

Genotype: *Stereopterum rotundum*, n. sp.

Stereopterum rotundum, n. sp.

Figure 8.

Fore wing: length, 12.8–13.5 mm.; width, 4.5–5 mm. Costal margin strongly curved, apex bluntly rounded; costal area with about 15 cross-veins; subcostal area with 6–8 long, sigmoidal cross-veins; Rs forked distally; MA unbranched or forked; MP with two or

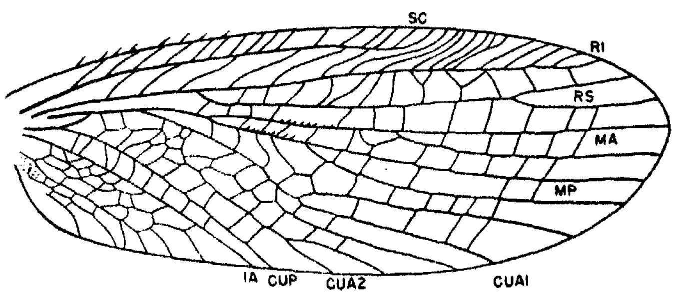


FIGURE 8. *Stereopterum rotundum*, n. sp. Drawing of fore wing, based on holotype. Lettering as in figure 1.

three terminal branches; CuA dividing into CuA1 and CuA2 shortly after the anastomosis with M, though the base of CuA2 is sometimes lost in net-work of cross-veins; CuA1 with two or three terminal branches; CuA2 unbranched or forked distally. The costal margin bears several stout spines, at least proximally; Rs, MA, and MP have about ten prominent hairs near the center of the wing; and the base of the anal area has a patch of smaller, stout hairs. Cross-veins highly variable in number and arrangement.

Hind wing and body unknown.

Holotype: No. 4922ab, Museum of Comparative Zoology; collected at the Elmo locality (lower layer) by F. M. Carpenter. This consists of a complete and well preserved fore wing.

Paratypes: Nos. 4956 and 4980, Museum of Comparative Zoology, complete fore wings except for anal area. No. 15634ab, Peabody Museum, Yale University, consiting of a complete fore wing.

This is a rare insect in the Elmo fauna. In addition to the types mentioned, I have seen only four other specimens. All of these eight fossils are from the lower layer of the limestone.

I have established a separate family for this species mainly on the basis of the anastomosis of CuA with the stem of M, which apparently represents an advanced stage in the evolution of the cubitus in this particular protorthopterous line. This appears to be a constant feature of the fore wing, for, although other venational details vary greatly, this is constant in the eight specimens at hand. Until the hind wing and body structure are known, it will not be possible to place this insect more precisely.

DEMOPTERIDAE, new family

Insects of medium size, related to the Liomopteridae. The fore wing was coriaceous and the veins thick. Sc terminated on the costal margin about two-thirds of the wing-length from the base; the costal area was about as wide as the subcostal area, its cross-veins numerous and irregular. The radius terminated before the apex of the wing, its sector arising before mid-wing and weakly branched at most; MA and MP separated at about the level of the origin of Rs; MP had many more branches than MA. Cu was formed as in the Liomopteridae, but CuA2 separated from CuA1 at about the level of the origin of Rs. CuA1 had several branches: 1A was close to CuP, and 2A was well developed, with several branches. Cross-veins were very numerous, forming an irregular network over many parts of the wing.

The hind wing and body structure are unknown.

Demopterum, new genus

Fore wing: costal area nearly uniform in width for its entire length, its cross-veins not markedly slanted; subcostal cross-veins at least slightly sigmoidal. Area between CuA and CuP with several irregular rows of cellules. Other characteristics as given under the species.

Genotype: *Demopterum gracile*, n. sp.

Demopterum gracile, n. sp.

Figure 9; plate 2, figure 2.

Fore wing: length, 18–21 mm., width, 5.5–6 mm.; costal margin nearly straight or slightly concave; costal area with 14–18 veinlets, rarely forked; subcostal cross-veins also numerous, more or less sigmoidal; Rs either unbranched or weakly forked distally; MA forked

distally; MP with five or six terminal branches, highly variable in arrangement; CuA with four or five terminal branches, also variable in form.

Hind wing and body unknown.

Holotype: No. 4961, Museum of Comparative Zoology, collected at the Elmo locality (lower layer) by F. M. Carpenter; this is a complete and well preserved fore wing.

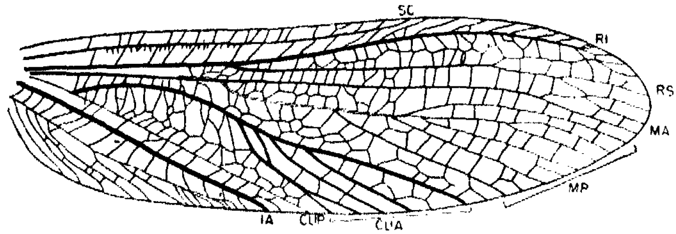


FIGURE 9. *Demopterum gracile*, n. sp. Drawing of fore wing, based on holotype. Lettering as in figure 1.

Paratypes: No. 15793, Peabody Museum, Yale University, collected at the Elmo locality by C. O. Dunbar. This consists of two fore wings slightly overlapping, and lacking the distal portions. No. 15562 (counterpart 15652), Peabody Museum; this is a complete fore wing. In addition to these, there is another specimen (No. 15646 Peabody Museum), consisting of the proximal half of a wing.

This is apparently a rare species in the Elmo fauna. On the basis of the evidence now at hand it belongs to the same group of Protorthoptera as the Liomopteridae and Chelopteridae, but the coriaceous texture of the fore wings, indicated by the thick veins, places it in a distinct family. This is also substantiated by the structure of the cubitus, for it is the only species in this group of Protorthoptera which does not have a proximal division of CuA.

The venation of *Demopterum gracile* is obviously subject to much variation,—at any rate, the differences in the patterns of cross-veins in the few known specimens are very striking. The longitudinal veins are apparently much more stable, showing only the usual amount of variation.

Family PHENOPTERIDAE, new name[1]

Small insects, related to the Liomopteridae. The fore wing was apparently membranous and delicate, though having a conspicuous reticulation of strong cross-veins. Hairs and spines were absent from

[1] New name for Lepiidae Sellards.

the wing. The subcosta terminated on the costa, about two-thirds the wing length from the base, the costal area containing numerous cross-veins, uniformly slanted and with little reticulation. The radius terminated well before the apex of the wing, its radius arising before midwing, and having only two or three branches. The media was forked to approximately the level of the origin of Rs, with few branches. The cubitus was formed as characteristic of this group of protorthopterous families, with CuA diverging anteriorly away from CuP and forking with two main branches (CuA1, CuA2). An anterior branch of CuA extended well along towards the apex of the wing. CuP and the three or four anal veins were unbranched. The distal parts of Rs, MA, MP, and CuA1, beginning at about midwing, were abruptly thickened.

The hind wing was about as long as the fore wing, and it also had a network of cross-veins, at least in the remigium. R, M and CuA arose from a single basal stem, CuA diverging just before M, and M before R. M separated into MA and MP just before midwing. CuA was a very heavy vein, branched distally as in the Liomopteridae. The anal area was apparently well developed, as in the preceding species, but its venation is almost unknown. The body structure is completely unknown.

This family was established by Sellards in 1909 for three species belonging to the genera *Lepium* and *Atava*. From my examination of his type specimens and from a study of many individuals in the Harvard and Yale collections, I am convinced that the two species of his genus *Lepium* represent only a single species, *elongatum*. *Atava*, on the other hand, does not belong to the same family; the unique species (*ovata*) for which the genus was established is known only by part of a hind wing. It is removed to a remote position from *elongatum* by the unbranched CuA, and since the fore wing is unknown, it should be placed in Protorthoptera "incertae sedis". Handlirsch also placed in the family with *Lepium* a species (*Permula lebachensis* Handl.) from the Permian of Germany. However, the fossil on which the species was based consists of a proximal fragment of a relatively large wing, some 50 mm. long. Since no features suggestive of *elongatum* are preserved in the fossil, there seems little justification for assigning it to the same family. It is undoubtedly protorthopterous, however, and hence should be referred to "incertae sedis" under that order.

Genus **Phenopterum**, new name

Lepium Sellards, 1909, Amer. Journ. Sci., (4) **27**: 156 (*nec Lepium* Enderlein, 1906, Spolia Zeylan., (14): 81. [Corrodentia]).

Fore wing: slender; costal area moderately broad proximally, much

narrowed distally, the costal margin being nearly straight; M forked slightly basad to level of origin of Rs; MA unbranched or forked; MP unbranched.

Hind wing: main veins with terminal branches much as in the fore wing, though MP was apparently forked distally. The conspicuous anterior branch of CuA arises at about midwing.

Genotype: *Lepium elongatum* Sellards.

Phenopterum elongatum (Sellards)

Figure 10.

Lepium elongatum Sellards, 1909, Amer. Journ. Sci., (4) **27**: 156, fig. 8
Lepium reticulatum Sellards, 1909, ibid., p. 156
Lepium sellardsi Handlirsch, 1919, Denkschr. Akad. Wiss., **96**: 32

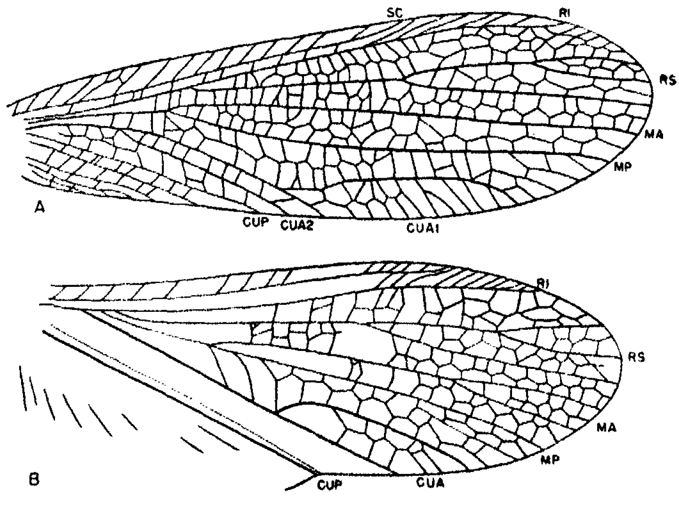


FIGURE 10. *Phenopterum elongatum* (Sellards). A, fore wing, based on specimen M. C. Z. 4931; B, hind wing, based on specimens M. C. Z. 4973 and 4970. Lettering as in figure 1.

Fore wing: 13.5–14 mm., width, 3.5–4.2 mm.; 20–25 costal veinlets, 10–15 cross-veins between Sc and R1; Rs usually with R2, R3, and R4 + 5, less often with R2 + 3 (about 25% of the specimens) and even less often with R4, R5 (10% of specimens); MA either undivided or forked into MA1 and MA2, about half of the number of specimens being in each category; MP unbranched in all known specimens; cross-veins forming an irregular network, highly variable in details, but nearly constant in general appearance.

Hind wing: length, 13 mm.; width, 3.5 mm. (remigium only). Rs with R2 + 3, R4 + 5; MA and MP either unbranched or forked distally; cross-veins forming a network like that of the fore wing; the anal area is unknown.

Type: since the type of *elongatum* is lost, I designate as the neotype, specimen 4931ab in the Museum of Comparative Zoology. This consists of a complete and well preserved fore wing collected by F. M. Carpenter at the Elmo locality.

Altogether, including Dr. Sellards' types, I have seen twenty-two specimens of this unusual insect. Of the twelve specimens contained in the Harvard collection, about half are from the upper layer. Some of the fore wings (such as M. C. Z. 4925, 4931, 4926, 4971 and P. M. 15637, 15583) are very well preserved. One specimen, M. C. Z. 4974, shows all four wings, but the venation is poorly preserved in all wings. Although there are several specimens of hind wings (M. C. Z. 4970, 4973; P. M. 15617, 15632), in all of them the anal area is folded over in such a way that its venation is obscure. In two of them (M. C. Z. 4973, 4970) it is possible to make out parts of the anal veins, as indicated in figure 10.

The complete absence of body structures in all specimens is remarkable, and probably means that the insect in general was delicate, with a weakly sclerotized integument.

The type of *reticulatum* consisted of a well preserved fore wing, differing from the type of *elongatum* by having an incomplete third branch to Rs. As indicated above, however, the number and arrangement of the branches of Rs are highly variable in this insect, no two specimens being alike. The longer R1, mentioned in Sellards' description of *reticulatum*, is due to the difficulty in determining just where R1 ends and the veinlets begin. As noted by Sellards, the type of *reticulatum* showed something of the anal area of the hind wing, but this was folded to such an extent that the venation was obscure.

L. sellardsi was established by Handlirsch, without diagnosis, for the unfigured hind wing which Sellards described as "*Lepium* (?) sp." Examination (1927) of this specimen, which consisted of the middle part of the remigium, convinced me that it had no peculiarities justifying specific separation from *elongatum*.

Family PROTEMBIIDAE

Small insects, related to the Phenopteridae. Fore wing slightly coriaceous; distal parts of Rs, MA and MP bordered by delicate lines on each side. The subcosta terminated on the costa, the costal space being very narrow. Rs arose at midwing, and M was forked before the level of the origin of Rs. CuA was formed as characteristic of

this group of Protorthoptera, but CuA2 was not differentiated from the rest of CuA, which had several distal branches, as in the Phenopteridae. The anal area was much reduced, only the first anal being present. The distal portions of Rs, MA and MP were bordered by delicate lines, resembling thin veins. The hind wing was about as long as the fore wing. M was unbranched at least to the middle of the wing; Rs arose near the base of the wing; CuA had a prominent distal fork, like that of the Lepiids. The anal area is incompletely known, but it was apparently much smaller than that of the Liomopteridae. The lines bordering Rs, MA and MP were present as in the fore wing, though somewhat weaker.

The body was large and long in proportion to the wings; the head small, with prominent eyes; the antennae long with about 28 segments. The prothoracic lobes were very small. The hind legs were much longer than the other two pair, but were apparently not modified for jumping. All tarsi were 5-segmented. The cerci were short, only about as long as the fore tarsi, and consisted of a few distinct segments.

This family was established by Tillyard in 1937 for *Protembia permiana* Till., which was known to him by the poorly preserved type specimen, and which he placed in a new suborder (Protembiaria) of the order Embiaria. Later the same year Tillyard also described another species from the Elmo deposit which he named *Telactinopteryx striatipennis* and placed in the family Probnisidae of the order Protoperlaria. A study of the type of *P. permiana* and of the numerous specimens of *T. striatipennis* in both Yale and Harvard collections convinces me that they are the same species. The evidence for this conclusion will be given below following the account of the species. Unfortunately, the generic name *Protembia,* which carries an erroneous phylogenetic implication, has priority over the more appropriate term, *Telactinopteryx*.

Genus *Protembia* Tillyard

Protembia Tillyard, 1937, Amer. Journ. Sci., (5) **33**: 243
Telactinopteryx Tillyard, 1937, ibid., 422

Fore wing: costal veinlets very short and few in number; beyond end of Sc there are several long veinlets between R and the costal margin; Rs with three terminal branches; MA and MP at least forked; cross-veins numerous in the central part of the wing, apparently absent in the region of the terminal branches of the main veins; cellules are only rarely formed.

Hind wing: Sc and R1 essentially as in the fore wing; Rs forked distally; MA and MP either unbranched or forked.

The body structure is described below under the species.

Protembia permiana Tillyard

Figure 11.

Protembia permiana Tillyard, 1937, Amer. Journ. Sci., (5) **33**: 245, figs. 1–3

Telactinopteryx striatipennis Tillyard, 1937, ibid., 422, figs. 8–10.

Fore wing: length, 7–7.5 mm. long, 2 mm. wide. 6–8 costal veinlets, 8–11 cross-veins between R1 and the wing margin; one or two cross-

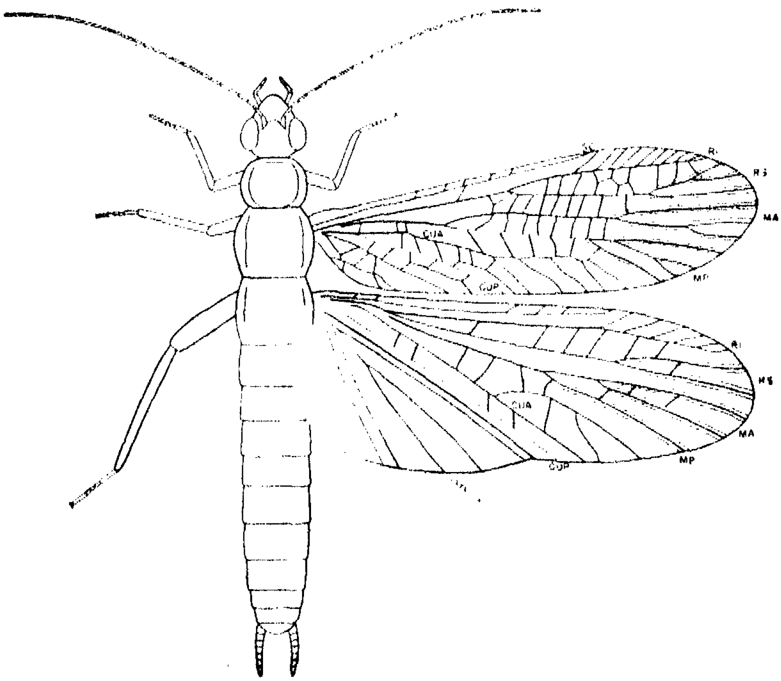


FIGURE 11. *Protembia permiana* Tillyard. Restoration based on specimens in Harvard and Yale collections. Lettering as in figure 1.

veins between R and Sc; Rs divided into R2, R3, R4 + 5; MA usually three branched, with either MA1 or MA2 bearing the extra fork; MP usually with three or four terminal branches; CuA1 usually with five terminal branches.

Hind wing: length, 6.8 mm., width, 2.5 mm., across anal area. Rs and MA usually with two branches, MP either unbranched or forked. Cross-veins are fewer than in fore wing, with almost no cellule formation.

Body structure: length of body, excluding cerci and antennae, 7–8 mm.; head small (1 mm. wide), with prominent eyes. Antennae relatively long (11 mm.), consisting of about 28 subequal segments, each about three times as long as wide. The mouth-parts are unknown, except for the palpi (probably maxillary), which are about .6 mm. long and include at least three segments. Thorax relatively long and narrow. The prothorax, which is a little broader than long (1 x 1.5 mm.), has small lateral extensions, much smaller than those of the Liomopterids or related insects; whether these extensions were coriaceous, as they appear to me, or membranous, as Tillyard thought, remains uncertain. The meso- and metathoracic segments are subequal, and a little longer than broad (1.5 x 1 mm.). The fore legs are of moderate size, extending about 3 mm. beyond the edge of the thorax; the tarsi 5-segmented, the first and last tarsomeres being long and subequal, the other three being much shorter and subequal. The mesothoracic legs are only slightly longer than the fore pair, with the same tarsal segmentation. Hind legs about twice as long as the fore pair; the tarsal segmentation is not visible in any specimen, but there is no reason to assume it differed from that of the other two pairs of legs. The abdomen, which is about as long as the head and thorax combined, terminates in a pair of short cerci (1 mm.), consisting of several (6–8) indistinct segments. None of the specimens at hand show an exserted ovipositor like that of some of the previously described species.

Holotype: No. 15507ab, Peabody Museum, Yale University. The fossil consists of a very indistinctly preserved whole specimen.

This is not a common species in the Elmo fauna. In the Yale collection there are apparently only four specimens, including the three types of *Telactinopteryx striatipennis* Till. In the Harvard collection there are thirteen specimens, with about equal numbers from the upper and lower layers of the limestone. Among the specimens in the Harvard collection are two exceptionally well preserved fore wings (nos. 4987ab, 4927), two good hind wings (nos. 4980, 4982), and several excellent whole specimens showing all wings and parts of the body (nos. 4978, 4979, 4985, 4986, 4988 and 4989).

The most remarkable feature of *Protembia* is the lines paralleling the distal parts of the main veins in both wings. Tillyard, who did not represent them quite correctly in his figure, termed them "striae or rays", but was unable to determine their nature. In most specimens they appear to be delicate creases in the wing membrane, but in one very well preserved fossil (M. C. Z. 4986) they are preserved like true veins—fine lines of cuticular material. Whatever their structure, they are interesting because in several families of Protorthoptera

the distal part of the wing is differentiated from the proximal part by a change in texture, in density or in appearance of the veins. This is seen in the Phenopteridae, for example, and more markedly in the Blattinopsidae, and will be discussed in the next paper in this series.

The above synonymy of *Telactinopteryx striatipennis* with *Protembia permiana* is based upon my examination of the types of these species as well as the additional material mentioned above. Since the types of *T. striatipennis* were very well preserved, there is no uncertainty about the characteristics of that species. Tillyard's account of *striatipennis* is misleading in two important respects, however, and it is necessary to discuss these before coming to the reasons for the synonymy. First, there are two of the longitudinal rays or striae between the apical branches of the veins instead of three as shown by Tillyard. His figure of the striae was actually correct except that the middle of his three striae was in reality a branch of the vein. Also these striae arise with the branches of the veins which they parallel, as indicated in the accompanying illustration. In the second place, the eyes of *striatipennis*, which Tillyard depicted as being small, were actually larger, Tillyard having been misled by the angle at which the head was placed in the paratype (no. 15559).

The unique type on which *Protembia permiana* was based is so poorly preserved that Tillyard's description of it was necessarily the result of interpretations of faint and vague markings on the rock matrix. My suspicions of the identity of *permiana* and *striatipennis* were aroused by the dotted lines shown in Tillyard's figure 2 (1937, p. 245) which paralleled the distal branches of the main veins, for, as drawn by him, they were precisely like those in specimens of *striatipennis*. My examination of the type of *Protembia* substantiated the conviction that the lines or striae were identical in the two fossils.

The venation of *permiana*, as depicted in Tillyard's figure 2 seems to be very different from that of *T. striatipennis*. However, Tillyard's figure of the venation, as stated in the caption,[2] is a *restoration* of the venation, without any indication of how much was restored. Comparison of Tillyard's restoration (figure 2) with the drawing of the venation in *striatipennis* included here (figure 11), shows that if Tillyard's vein R4 + 5 were attached to M instead of to R2 + 3, the venation would be that of *striatipennis!* Actually, of course, the origin of Tillyard's vein "R4 + 5" is not discernible in the type of *permiana*, its attachment to R being a part of the restored area.

If we add to the foregoing the fact that the head and eyes of *Protembia permiana*, as well as the size and general form of the body and

[2] It should be noted that the caption for figure 2 was accidentally placed under figure 8.

wings, are precisely like those of *striatipennis*, the need for synonymizing the latter becomes obvious.

The relationships of *Protembia*, though by no means clear, seem to be with the Phenopteridae. Our knowledge of the latter insects is not nearly so extensive as that of *Protembia*, but the peculiar change in the appearance of the distal branches of the veins in *Phenopterum* is highly suggestive of the striated veins occurring in *Protembia*. At any rate, with the present additions to our knowledge of *Protembia*, there seems to be no evidence whatsoever for relating it to the Embioptera. The conclusions which Tillyard (1937) and Davis (1940) reached on the basis of this fossil, including the establishment of the new suborder Protembiaria (Tillyard) or Protembioptera (Davis), are consequently no longer valid. With the elimination of *Protembia* from the Embioptera, the oldest record of the order reverts to the Oligocene (Baltic amber). Zalessky named (1937) two species of insects from the Permian of Russia, *Tillyardembia biarmica* and *T. antennaeplana* and, apparently influenced by Tillyard's paper, assigned them to the order Embioptera. Unfortunately, he does not describe the venation of either of these species, but the few characteristics mentioned make it obvious that they cannot be referred to the Embioptera. Until more information about them is available, they can only be assigned to the Order Protorthoptera, "incertae sedis."

Relationships of These Families

As previously indicated in my introductory comments on the Protorthoptera (1943), I shall not anticipate here the conclusions of my current study of the Carboniferous members of the order. The following discussion is an attempt only to indicate the relationships of the Liomopteridae and other families treated in the foregoing pages with certain other Permian groups. However, since most of the latter have been described by Martynov, a brief account of his concept of the Protorthoptera is necessary. In his last (1938) general survey of insect phylogeny, Martynov dropped completely the term "Protorthoptera" for a taxonomic category and attempted to separate into three widely divergent lines the families formerly placed under that order. Some of the families were transferred to the existing order Orthoptera (Saltatoria), but most were assigned to two superordinal groups. One of these, the Blattopteroidea, included the Protoblattaria and Blattaria; the other, the Plecopteroidea, contained the extinct orders Paraplecoptera and Protoperlaria, in addition to the existing order Perlaria. Whether or not this division of the old order Protorthoptera will stand up as the insects become better known remains to be seen.

The families Liomopteridae and Lepiidae (Phenopteridae), which have been redescribed above, were placed by Martynov in the order Paraplecoptera. I concur with his grouping of these into a single phylogenetic line, quite apart from the question of whether that line represents an order or suborder; and I also include in the same group with these the other families described above. Although the position of the family Protembiidae is not so clear as that of the others, I believe the available evidence suggests that it is only a more specialized member of this same line. In the following discussion I propose first, to consider the characteristics common to the six families treated in this paper; second, to consider their differences; and finally, to compare all of these features with those of the Lemmatophoridae (Protoperlaria) and of certain other Permian families placed by Martynov in the Protoblattaria and Paraplecoptera.

The characteristics common to the families treated in the foregoing pages occur in the fore and hind wings as well as the body.

Fore wings.

1. The most obvious venational feature common to all is the basic structure of the cubitus. This consists of a strong, convex CuA and a weak, concave CuP, which is straight or nearly so, without branches. In most of the species CuA has two distinct branches, CuA1 and CuA2, the latter arising much nearer the base of the wing than the branches of CuA1. In two of the families, Demopteridae and Protembiidae, there is no distinct CuA2, this vein apparently having lost its identity by arising distally. In all the families CuA is entirely independent of M or MP, with the exception of the Stereopteridae, in which CuA is clearly anastomosed for a short distance with M.

2. Another obvious characteristic common to all is the weak nature of the vein MP, between its separation from MA and its first branch. Although this is more clearly seen in those species which have other veins especially heavy (as the Demopteridae), it can be observed to a greater or lesser degree in the other families.

3. The anal veins are also essentially alike. 1A is a strong, straight vein, without branches, whereas 2A is distinctly branched, often several times.

Hind wings. (Known only in the Liomopteridae, Chelopteridae, Protembiidae and Phenopteridae.)

4. The anal area of the hind wing is similar in all these families, though the anal fan is slightly smaller in the Protembiidae.

5. The basal connection of Rs, M, and Cu are similar, though showing slight differences. In the Liomopteridae, Protembiidae, and Phenopteridae Rs and M are independent basally, but in the Chelopteridae they appear to coalesce. CuA is independent of MP in all

families, though it probably touches M at the base. It also has a prominent distal fork, with the anterior branch divergent, in all the families except Chelopteridae.

Body Structures.

6. The prothorax is probably essentially alike in these six families; at any rate, this is true of the three families of which the prothorax is known. There is a distinct pronotum, apparently heavily sclerotized, surrounded by a flat marginal area, having much generic variation in shape. In the Liomopteridae the marginal area is large and in *L. ornatum* it has a covering of fine microtrichia, which are not present on the pronotum proper. This has every appearance of being membranous. In *L. sellardsi* the hairs are even longer and occur also on the pronotum. In the Chelopteridae and Protembiidae, the marginal area is much narrower, lacks the hair covering and appears to be more coriaceous than membranous.

7. The leg structure of the families mentioned is surprisingly uniform. The hind pair in all is distinctly longer than the others, though not modified for jumping, and so far as known the tarsal segmentation is alike in all legs, not only as to the number of segments but even to the relative sizes of the segments.

In contrast to the foregoing characteristics, which are fairly uniform throughout these families, there are several features which show marked diversity. These are especially interesting, since they indicate something of the lines of evolution which have developed within this particular group of families. These differences may be summarized as follows:

1. Texture of fore wing. In the Liomopteridae the fore wing is clearly membranous, with a covering of microtrichia; the latter may be moderately long, as in *Liomopterum*, or very short, as in *Tapopterum*. In others, as Stereopteridae and Demopteridae, the wing is distinctly coriaceous and bears at most a few long and thick macrotrichia. This transition from membranous to coriaceous wings seems to have taken place, however, without any apparent change in the longitudinal veins.

2. Cross-veins. The number and general pattern of the cross-veins are very different, even among the genera of the Liomopteridae. The pattern varies from a moderately open one in *Liomopterum* to a much denser condition in *Tapopterum*, Chelopteridae and Demopteridae, with a true reticulation in Phenopteridae. The cross-veins in Chelopteridae show a marked differentiation in various parts of the wings.

3. Antennae. These show surprising variation in the fossils being considered, at least so far as segmentation is concerned. In *Lio-*

mopterum the segments are of nearly uniform size and shape, whereas in *Chelopterum* the distal segments are fully five times as long as the basal ones.

4. Cerci. These also show an unexpected amount of variation. In *Liomopterum* they are fully as long as the whole abdomen; in the female of *Chelopterum* and in *Protembia* they are only about as long as a single abdominal segment. The chelicerate cerci in *Chelopterum* are also noteworthy, since similar modifications are not known in any other Permian insect.

It should be noted at this point that, although a prominent exserted ovipositor is actually known only in one family (Chelopteridae), a similar ovipositor probably exists in the females of all the above families. The odds are so much against finding a specimen which shows the ovipositor that little significance can be attached to the lack of such material.

The similarity between some of the "Protorthoptera" and the Protoperlaria has been discussed in several papers by Martynov (1930), Tillyard (1937) and Carpenter (1935, 1943). The conclusion which I reached and to which Tillyard agreed was that the real distinction between the Protoperlaria and its allies was to be found in the nymphs: those of the Protoperlaria were modified for an aquatic life, while those of the other groups (protorthopterous) were entirely terrestrial. Such a distinction, however, has no practical application to the classification of the fossils concerned, unless some correlation can be made with adult characteristics. The difficulty has perhaps resulted in part from the fact that, although a great deal has been known about the wing and body structure of the Protoperlaria, almost nothing has been known about the related protorthopterous groups. The fossils on which the present paper is based have greatly improved this situation. The differences and similarities between the adult Protoperlaria and the families described above are as follows:

Wings. The marked similarity between the fore wings of the Protoperlaria and those of the Liomopteridae makes it seem highly improbable that isolated fore wings can be placed with certainty in either one or the other of these categories. It is true that there are fewer cross-veins in the fore wing of any of the Protoperlaria than there are in *Liomopterum*, which has the smallest number of any of the families considered here; but the difference is so small, at least in the case of *Artinska* (Protoperlaria), that its significance is questionable. Like the Liomopteridae, the Protoperlaria have a weak MP from its origin to its first fork, and also have the same general form of cubitus. The anal area of the fore wing seems to offer a possible lead. In all the families described in this paper, the anal veins are more numerous

and more extensive than in the Protoperlaria; the only exception to this is *Liomopterum ornatum*, which has anal veins like those of the Protoperlaria. The fore wings of the latter are uniform in texture, being membranous and covered with microtrichia. Although this is true of the Liomopteridae, it is not of the Chelopteridae and Demopteridae, which have coriaceous fore wings. The hind wings of the Protoperlaria and of the Liomopteridae, Chelopteridae, Phenopteridae and Protembiidae present several differences which I believe are significant. In the latter series of families, the anal fan is larger than that of any of the Protoperlaria (Lemmatophoridae) and includes many more anal veins. Furthermore, in all the Lemmatophoridae, the radial sector is coalesced with MA, even in those genera (like *Lemmatophora*) in which no such coalescence occurs in the fore wing. In none of the four families mentioned above is there any coalescence of these veins.

Body. In the Protoperlaria, the paranotal lobes of the prothorax are true, lateral lobes, independent of each other. In the Liomopteridae, Chelopteridae and Protembiidae, the lobes are no longer strictly lateral or independent; they appear to have extended along the mid-line of the thorax, forming a continuous ring around the pronotum proper. The area is membranous in the more generalized forms (as Liomopteridae), and has the same covering of microtrichia as the fore wings; in the more specialized families, at least in the case of those having coriaceous fore wings, this marginal ring has become more coriaceous. The Liomopteridae offer a particularly interesting transition between the paranotal lobes such as are found in the Palaeodictyoptera, Protoperlaria and other extinct orders, and the pronotal discs, such as occur in the roaches. It seems very probable that the roach pronotum has formed through similar stages in its development. As a final difference between the Protoperlaria and Liomopteridae there remains to be mentioned the occurrence of the small lateral flaps on the abdomen of the Protoperlaria, which have been interpreted as vestiges of the gills possessed by the nymphs. These structures are clearly absent in the adults of the Liomopterids.

As a general summary of the relationships of the Protoperlaria on the one hand and the Liomopteridae, etc., on the other, we may conclude that, although these groups are without doubt closely related, the Liomopterids are more highly specialized in many ways, having a modification of the paranotal lobes, larger anal fan on the hind wing and, at least in some families, a coriaceous fore wing.

It is necessary, at this point, to consider some of the Permian insects described from other deposits which seem to be related to the Liomopteridae. Most of these have been collected in Russian deposits

and described by Martynov. The family Sylviodidae was established by Martynov for two genera, *Sylviodes* and *Parasylviodes*, each of which is based on a single specimen. Unfortunately, only a few of the longitudinal veins are known, and none of the cross-veins except in the costal area. The venation that is present does suggest relationship with the Liomopteridae, and this is further indicated by the prothorax of *Parasylviodes*. This fossil shows clearly the oval marginal area like that of *Liomopterum*. Martynov placed this family in the Protoperlaria, but on the basis of the structure of the prothorax and the indication of many cross-veins in the fore wing, I refer this to the Protorthoptera, along with Liomopteridae. The family Sylvophlebiidae, which Martynov placed in the Paraplecoptera, is probably close to the Phenopteridae, although here again the anal area of the fore wing and the entire hind wing are unknown. The prothorax includes a small marginal area, which is continuous posteriorly and probably anteriorly. The family Camptoneuritidae, which Martynov also referred to the Paraplecoptera, is known from a single fore wing. This is well preserved and is especially interesting because it shows some faint lines like those of *Protembia*, bordering the distal part of the longitudinal veins. Of all the families described from other Permian deposits, the Ideliidae seems to be the closest to the Liomopteridae and the Phenopteridae. Although a number of genera of Ideliidae have been established, only the fore wings have been found. Probably, when their hind wings and body structure are known, a review of the generic and family classification of all these species will be necessary.

REFERENCES

CARPENTER, F. M.

1935. The Lower Permian insects of Kansas. Part 7. The order Protoperlaria. Proc. Amer. Acad. Arts Sci., **70**: 103–146.

1943. The Lower Permian insects of Kansas. Part 9. The orders Neuroptera, Raphidiodea, Caloneurodea and Protorthoptera (Probnisidae), with additional Protodonata and Megasecoptera. Proc. Amer. Acad. Arts Sci., **75**: 55–84.

1948. A Permian insect from Texas. Psyche, **55**: 101–103.

DAVIS, C.

1940a. Taxonomic notes on the order Embioptera. XX. The distribution and comparative morphology of the Embioptera. Proc. Linn. Soc. N. S. Wales, **65**: 533–542.

1940b. Family classification of the order Embioptera. Ann. Ent. Soc. Amer., **33**: 677–682.

HANDLIRSCH, A.

1919. Revision der paläozoischen Insekten. Denkschr. Akad. Wiss. Wien, **96**: 1–82.

MARTYNOV, A. V.

1928. Permian fossil insects of North-east Europe. Trav. Mus. Géol. Acad. Sci. URSS., **4**: 1–118.

1930. Permian fossil insects from Tikhije Gory. Order Miomoptera. Second part. Bull. Acad. Sci. URSS., **1930**: 1115–1134.

1937. Permian fossil insects from Kargala and their relationships. Trav. Inst. Paléont., **7**: 1–92.

1938. Etudes sur l'histoire géologique et de phylogénie des ordres des insectes (Pterygota). Trav. Inst. Paléont., **7**: 1–148.

1940. Permian fossil insects from Tshekarda. Trav. Inst. Paléont., **11**: 1–62.

TILLYARD, R. J.

1937a. Kansas Permian insects. Part 18. The order Embiaria. Amer. Journ. Sci., (5) **33**: 241–251.

1937b. Kansas Permian insects. Part 19. The order Protoperlaria (cont'd.). The family Probnisidae. Amer. Journ. Sci., (5) **33**: 401–425.

SELLARDS, E. H.

1909. Types of Permian insects. Part 3. Megasecoptera, Oryctoblattinidae and Protorthoptera. Amer. Journ. Sci., (4) **27**: 151–173.

ZALESSKY, G.

1937. Ancestors of some groups of present-day insects. Nature, **140**: 847.

ZALESSKY, M. D.

1929. Sur un nouveau Protorthoptère du Permien de Kama. Ann. Soc. Géol. Nord., **54**: 20–24.

Explanation of Plates

Plate 1.

Figure 1. *Liomopterum ornatum* Sellards. Photograph of fore wing, showing color markings. (Specimen no. 4828, Museum of Comparative Zoology, × 11).

Figure 2. *Liomopterum elongatum* (Sellards). Photograph of fore wing, showing color markings. (Specimen no. 15612, Peabody Museum, × 8).

Plate 2.

Figure 1. *Tapopterum celsum* n. sp. Photograph of fore wing, showing color markings. (Specimen no. 4930, Museum of Comparative Zoology, × 7.5).

Figure 2. *Demopterum gracile* n. sp. Photograph of fore wing. (Specimen no. 4961, Museum of Comparative Zoology, × 9).

Plate 3.

Figure 1. *Chelopterum peregrinum* n. sp. Photograph of fore wing, showing color markings. (Specimen no. 15645, Peabody Museum, × 6.5).

Figure 2. *Chelopterum peregrinum* n. sp. Photograph of end of abdomen of male, showing curved cerci. (Specimen no. 4903, Museum of Comparative Zoology, × 25).

PLATES

PLATE 1

PLATE 2

PLATE 3

Proceedings of the American Academy of Arts and Sciences

Vol. 78, No. 5, P. 221–252—August, 1950

Summer Number

RECORDS OF MEETINGS
FROM OCTOBER 1949 TO MAY 1950

American Academy of Arts and Sciences

OFFICERS AND COMMITTEES FOR 1950–1951

President
HOWARD MUMFORD JONES

Vice-Presidents

Class I
JEROME C. HUNSAKER

Class II
IRVING W. BAILEY

Class III
ROBERT B. STEWART

Class IV
WILLIAM A. JACKSON

Secretary
HENRY B. PHILLIPS

Treasurer
HORACE S. FORD

Librarian
ERNEST H. HUNTRESS

Editor
TAYLOR STARCK

Executive Officer
RALPH W. BURHOE

Councillors

Class I		Class II
JOSEPH H. KEENAN	*Terms expire 1951*	PAUL C. MANGELSDORF
ISADORE AMDUR	*Terms expire 1952*	ARLIE V. BOCK
EDWIN H. LAND	*Terms expire 1953*	FRANCIS O. SCHMITT
FRED L. WHIPPLE	*Terms expire 1954*	MARTIN J. BUERGER
Class III		**Class IV**
HARVEY H. BUNDY	*Terms expire 1951*	WILLIAM G. CONSTABLE
KEYES DEW. METCALF	*Terms expire 1952*	HENRY R. VIETS
W. RUPERT MACLAURIN	*Terms expire 1953*	GEORGE W. SHERBURN
MARK DEW. HOWE	*Terms expire 1954*	WILLARD V. O. QUINE

STANDING COMMITTEES

The House Committee
CHESTER M. ALTER, *Chairman*

CHARLES H. TAYLOR — JOHN B. WILBUR

The Committee on Membership
HOWARD M. JONES, *Chairman, ex officio*

Class I		Class II
KENNETH T. BAINBRIDGE	*Terms expire 1951*	SAMUEL A. LEVINE
WILLIAM T. MARTIN	*Terms expire 1952*	JOHN R. LOOFBOUROW
Class III		**Class IV**
ERWIN D. CANHAM	*Terms expire 1951*	WILBUR K. JORDAN
ARTHUR N. HOLCOMBE	*Terms expire 1952*	CLYDE K. M. KLUCKHOHN

The Committee on Meetings

Howard M. Jones, *Chairman, ex officio*
Henry B. Phillips, *Secretary, ex officio*

Class I
Avery A. Morton
Jerome C. Hunsaker, *ex officio*

Class II
Frederick L. Hisaw
Irving W. Bailey, *ex officio*

Class III
Mark DeW. Howe
Robert B. Stewart, *ex officio*

Class IV
Henry A. Murray, Jr.
William A. Jackson, *ex officio*

The Committee on Finance

Horace S. Ford, *Chairman, ex officio*

Ralph E. Freeman
Jerome C. Hunsaker
Henry P. Kendall
Henry L. Shattuck

The Auditing Committee

Thomas H. Sanders
Donald S. Tucker

The Committee on Publication

Taylor Starck, *Chairman, ex officio*

Ernest H. Huntress
Kenneth B. Murdock
Kenneth V. Thimann
Thomas North Whitehead

The Permanent Science Fund Committee

Hudson Hoagland, *Chairman*

Gustavus J. Esselen
A. Baird Hastings
Donald H. Menzel
Edward L. Moreland
Talcott Parsons
Julius A. Stratton

The Rumford Committee

Harlow Shapley, *Chairman*

Percy W. Bridgman
Arthur C. Hardy
George R. Harrison
Joseph H. Keenan
Edwin H. Land
Francis O. Schmitt

The C. M. Warren Committee

Frederick G. Keyes, *Chairman*

Edwin J. Cohn
Louis F. Fieser
Charles A. Kraus
Eugene M. Landis
Avery A. Morton
Walter C. Schumb

The Amory Prize Committee

Edwin B. Wilson, *Chairman*

William B. Castle
Roy G. Hoskins
Gregory Pincus
George W. Thorn
George B. Wislocki
S. Burt Wolbach

SPECIAL COMMITTEES ACTIVE DURING 1949-1950

Committee on the Conservation of Museum Objects

W. G. CONSTABLE, *Chairman*

CHESTER M. ALTER
HORACE S. FORD

Committee on International Relations

I. AMDUR, *Chairman*

WILLIAM G. CONSTABLE
WILLIAM T. MARTIN
HUDSON HOAGLAND
TAYLOR STARCK

Nominating Committee

PHILIP FRANKLIN, *Chairman*

JOHN G. BEEBE-CENTER
CALVERT MAGRUDER
FREDERICK K. MORRIS

Committee on Planning and Development

EDWIN H. LAND, *Chairman*

MASON HAMMOND
RALPH LOWELL
MILTON E. LORD
GEORGE C. SHATTUCK

Committee on Quartermaster Corps Laboratories

ROBERT B. STEWART, *Chairman*
GEORGE C. SHATTUCK

Committee on Revision of Statutes

JOHN W. M. BUNKER, *Chairman*

CHESTER M. ALTER
I. AMDUR

Committee on School Science

R. BRUCE LINDSAY, *Chairman*

CHARLES H. BLAKE
PHILIP FRANKLIN
JOHN T. EDSALL
EDWIN H. LAND (through March)
ROBERT ULICH (from March)

Associates

ALBERT E. NAVEZ
JOHN G. READ
FLETCHER G. WATSON

Committee on Unity of Science

P. W. BRIDGMAN, *Chairman*

HORACE S. FORD
PHILIPP FRANK

RECORDS OF MEETINGS

October 19, 1949—Stated Meeting

The One Thousand Three Hundred and Thirty-sixth Meeting of the Academy convened in its House on October 19, 1949, and was called to order by the President at 8:25 P. M.

There were present fifty Fellows and thirteen guests.

The records of the meeting of May 11 were read and approved.

The Secretary announced that the Council approved sixteen grants-in-aid from the Permanent Science Fund and one grant-in-aid from the Rumford Fund at its meeting this evening.

The Secretary reported the announcement of a Botanical Congress in Stockholm to be held in 1950.

The Secretary announced the election by the Council of Jerome C. Hunsaker (I:4) to fill the office of Vice-President of Class I for the remainder of the unexpired term left vacant by the death of Mr. R. G. D. Richardson.

The President announced the publication of "Health Services for Massachusetts Children" by Lendon Snedeker by the Academy for the Massachusetts Study of Child Health Services.

The President spoke on the status of the Academy upon its reaching the year of its 170th anniversary.

Recently elected Fellows were introduced as follows: James Walter Wilson (II:3) by A. B. Dawson; Edward Story Taylor (I:4) by J. H. Keenan; Charles Fayette Taylor (I:4) by C. R. Soderberg; Phillips Ketchum (III:1), William Henry Claflin, Jr. (III:4) by H. S. Ford; Willard Van Orman Quine (IV:1) by P. Frank; Lloyd DeW. Brace (III:4) by F. C. Gray; Mason Hammond (IV:2) by W. C. Greene; Fritz Albert Lipmann (I:3) by A. B. Hastings; Edwin Bennett Astwood (II:3), Herrman Ludwig Blumgart (II:4), by S. A. Levine; Reed Clark Rollins (II:2) by R. H. Wetmore; Van Wyck Brooks (IV:4), Richard Harrison Shryock (IV:2) by H. M. Jones.

The following communication was presented:

Henry M. Silver: *The Publication of Original Research Materials.*

The meeting was dissolved at 10:12 P. M.

November 9, 1949—Stated Meeting

The One Thousand Three Hundred and Thirty-seventh Meeting of the Academy convened in its House on November 9, 1949, and was called to order by the President at 8:23 P. M.

There were present seventy-one Fellows and forty guests.

The records of the meeting of October 19 were read and approved.

The Secretary announced that a Committee on Revisions to the Statutes (John W. M. Bunker, Chairman, C. M. Alter, and I. Amdur) had been created by the Council; that the Council had nominated Messrs. Hudson Hoagland and S. S Stevens for election as Trustees by the Institute for the Unity of Science; and that of the ninety-nine Fellows and five Foreign Honorary Members elected by the Academy at its May meeting, ninety-five Fellows and five Foreign Honorary Members had accepted; three had declined election as Fellows, and one was disqualified under the Statutes because of non-acceptance.

Recently elected Fellows were introduced as follows: Millar Burrows (IV:1) by H. J. Cadbury; Arthur Grinnell Rotch (III 4) by A N. Holcombe; Esther Forbes (IV:4) by H. Hoagland; Nathaniel Herman Frank (I:2), Hans Mueller (I:2), Jerrold Reinach Zacharias (I:2) by J. C. Slater; Wendell Hinkle Furry (I:2) by E. C. Kemble; Arthur Thomas Ippen (I:4) by T. K. Sherwood; Otto Krayer (II:3) by J. C. Aub; John Torrey Norton (I:4) by R. S. Williams; Lucien Price (IV:4) by E. D. Canham.

Dr. Henry R. Viets reported briefly on the work of a UNESCO committee on abstracting of scientific papers, on which he represented the American Medical Association at Paris this summer.

Mr. Ernest H. Huntress reported on his tour through northern Europe during the summer and his impressions of the scientific section of UNESCO.

The following communication was presented:

I. I. Rabi: *The Race for Atomic Armament.*

The meeting was dissolved at 9:50 P. M.

December 14, 1949—Stated Meeting

The One Thousand Three Hundred and Thirty-eighth Meeting of the Academy convened in its House on December 14, 1949, and was called to order by the President at 8:20 P. M.

There were present sixty-five Fellows and thirty-four guests.

The records of the meeting of November 9 were read and approved.

The Secretary reported that the Council had approved one grant-in-aid from the Rumford Fund.

The Secretary announced that the special Committee on International Relations was continued for another year by the Council.

Recently elected Fellows were introduced as follows: S. Bruce Black (III:4) by E. B. Wilson; Lawrence Rogers Blinks (II:2) by G. H. Parker; Oscar James Campbell (IV:3) by G. W. Sherburn; Robert Peter Tristram Coffin (IV:4) by E. Weeks, Jr.; David Glendenning Cogan (II:4) by F. H. Verhoeff; Robert Edward Gross (II:4) by S. A.

Levine; Kenneth Scott Latourette (IV:2) by A. D. Nock; Witold Hurewicz (I:1) by P. Franklin; Louis Martin Lyons (III:4) by A. N. Holcombe.

Mr Arthur T. Ippen (I:4) reported on his recent attendance at the International Association for Hydraulic Research at Grenoble and at the Permanent International Association of Navigation Congresses at Lisbon.

Dr. David G. Cogan (II.4) reported on his findings on delayed effects of the Hiroshima atom bomb explosion in respect to development of radiation cataract in eyes of persons who had not succumbed to the short duration, high intensity radiation; also his personal observations on social and political conditions in Japan.

Introduced by Mr. Shapley, Chairman of the Rumford Committee, Ira S. Bowen, the Rumford medalist for 1949, received at the hand of the President the Rumford gold and silver medals for his solution of the mystery of nebulium and for other outstanding work in spectroscopy.

The following communication was presented:

Ira S. Bowen: *The Two Hundred-Inch Hale Telescope.*

The meeting was dissolved at 10:04 P. M.

January 11, 1950—Stated Meeting

The One Thousand Three Hundred and Thirty-ninth Meeting of the Academy convened in its House on January 11, 1950, and was called to order by the President at 8.20 P. M.

There were present fifty-eight Fellows and eighteen guests.

The records of the meeting of December 14 were read and approved.

The Secretary reported for the Council the appointment of the following members of the Committee on International Relations to serve for one year: I. Amdur (I:3) Chairman, W. G. Constable (IV:4), H. Hoagland (II:3), W. T. Martin (I:1), and T. Starck (IV:3).

Recently elected Fellows were introduced as follows: Bernard Augustine DeVoto (IV:4) by K. B. Murdock; Sidney Farber (II:4) by S. B. Wolbach; John Wells Farley (III:4) by E. D. Canham; Carroll Louis Wilson (III:4) by J. W. M. Bunker.

Dr. John T. Edsall (I:3) told of his trip to Denmark and England and particularly concerning progress made by A. V. Hill of University College, London, in the measurement of energy transformation in muscle.

Mr. Milton E. Lord (IV:4) recounted his impressions, as a member of the World Town Hall Seminar, concerning library conditions around the world, and in addition offered observations on war devastation, displacement of persons, overpopulation, need for increased food pro-

duction, education and the failure to use the potential of women. He called attention also to the fact that the healthy respect which the rest of the world holds for the United States is tinged at the same time with a certain degree of dislike and distrust.

The following communication was presented:

P. W. Bridgman: *Some Philosophical Implications of Physics.*

The meeting was dissolved at 10 P. M.

February 8, 1950—Stated Meeting

The One Thousand Three Hundred and Fortieth Meeting of the Academy convened in its House on February 8, 1950, and was called to order by the President at 8:30 P. M.

In the absence of the Secretary, the Editor served in his stead.

This meeting had been designated as Ladies' Night, and there were present fifty-four Fellows and ninety-six guests.

The records of the meeting of January 11 were read and approved.

The Editor reported that the Council approved one grant-in-aid from the Rumford Fund.

The Editor announced that the Council authorized the President to appoint a Committee on Planning and Development.

Recently elected Fellows were introduced as follows: Archer Taylor (IV:3) by T. Starck; Selman Abraham Waksman (II:2) by C. S. Keefer.

Mr. Kirtley Mather (II:1) reported on the status of education and science as he found them in Yugoslavia last August. He pointed out that, as one would naturally expect under the circumstances, there was great emphasis on the applications of science and engineering techniques and practically no pure research. He presented his notes made in interviews with officials in agriculture, medicine, and electric power. In each case there was a lack of equipment, technical literature, and adequately trained personnel. In each case, also, the officials seemed to wish to send their young men for training in the United States.

The following communication was presented:

Paul Hindemith: *Music Theory.*

The meeting was dissolved at 10:00 P. M.

March 8, 1950—Stated Meeting

The One Thousand Three Hundred and Forty-first Meeting of the Academy convened in its House on March 8, 1950, and, in the absence of the President and the four Vice-Presidents, was called to order by the Secretary at 8:27 P. M.

There were present thirty-one Fellows and twenty-nine guests.

The records of the meeting of February 8 were read and approved.

The Secretary reported that the Council had approved appropriations for the coming fiscal year and that these would be presented to the membership at the Annual Meeting.

The Secretary announced that the President had appointed the following Nominating Committee: Philip Franklin of Class I (Chairman); Frederick K. Morris of Class II; Calvert Magruder of Class III; and John G. Beebe-Center of Class IV.

Recently elected Fellows were introduced as follows: Leland Matthew Goodrich (III:2), James Blaine Hedges (IV:2) by C. J. Ducasse.

Prof. R. B. Lindsay, Chairman of the Committee on School Science, presented as guests of the Academy the following high-school seniors who were outstanding in their respective states in their achievements in the 1950 national Science Talent Search:

Lammot Copeland, Jr., Brooks School, North Andover, Massachusetts
H. Randall Deming, Bellows Free Academy, St. Albans, Vermont
Harold O. Douglass, Jr., Greenwich High School, Greenwich, Connecticut
Donald E. Eckels, Laconia High School, Laconia, New Hampshire
David A. Gray, New Canaan High School, New Canaan, Connecticut
James C. Lafferty, Bassick High School, Bridgeport, Connecticut
Robert Morris, Phillips Exeter Academy, Exeter, New Hampshire
Robert P. Rafuse, Newton High School, Newtonville, Massachusetts
William G. Tifft, Seymour High School, Seymour, Connecticut
Edward J. Wawszkiewicz, Mount St. Charles Academy, Woonsocket, Rhode Island

The following communication was presented:

Norbert Wiener: *Cybernetics.*

The meeting was dissolved at 9:45 P. M.

April 12, 1950—Stated Meeting

The One Thousand Three Hundred and Forty-second Meeting of the Academy convened in its House on April 12, 1950, and was called to order by the President at 8:25 P. M.

In the absence of the Secretary, the Librarian served in his stead.

There were present fourteen Fellows and seven guests.

The records of the meeting of March 8 were read and approved.

The Librarian reported that the Council had approved nine grants-in-aid from the Permanent Science Fund.

Mr. C. Fayette Taylor (I:4) reported on his visit to Zürich, Switzerland, last summer in which he indicated that the successful Swiss

economy was due in large part to the export of manufactured materials. He thought that reasons for this include the excellent technical education both at the trade school and university level and the specialization in complicated items difficult to manufacture, and mentioned among other things the unique production of large gas turbine engines generating up to 27,000 kilowatts. From brief visits to France, Italy and the Benelux countries, it was his opinion that Communism in Europe was rather directly proportional to the percentage of the population which is poor, hungry, badly housed, and that our best weapon against Communism is economic help.

The following communication was presented:

Herbert Dieckmann: *The Importance of the* Fonds Vandeul *Manuscripts for Studies of Diderot and the 18th Century.*

The meeting was dissolved at 10:05 P. M.

May 10, 1950—Annual Meeting

The One Thousand Three Hundred and Forty-third Meeting of the Academy convened in its House on May 10, 1950, and, in the absence of the President, was called to order by the Vice-President for Class I, Mr. Hunsaker, at 8:30 P. M.

There were present thirty-three Fellows and thirteen guests.

The records of the meeting of April 12 were read and approved.

On the recommendation of the Council, the annual assessment of $15 for 1950–1951 and the following appropriations were approved:

From the General Funds:		
Salaries and Pensions	$12,667.22	
General Administration	5,175.00	
House Maintenance	10,485.00	
President's Expense	300.00	
Treasurer's Expense	700.00	
		$29,327.22
From the Restricted Funds:		
Amory Fund Committee	$ 100.00	
Permanent Science Fund Committee	55,000.00	
Publication Committee	8,000.00	
Rumford Committee	5,000.00	
Warren Fund Committee	1,500.00	
		69,600.00
From the Current Expense Fund:		
For tables and chairs for the Lounge		1,000.00
		$99,927.22

Recently elected Fellows were introduced as follows: John Cobb Cooper (III:1) by George Pierce Baker; Edward Wheeler Dempsey (II:3), Lars Onsager (I:3) by John T. Edsall.

The annual reports were presented and accepted, as appended below under ANNUAL REPORTS. New members and officers and committees were elected, as given below under ELECTIONS.

The following communication was presented:

Otto K. Koppen: *The Development of the Helioplane.*

The meeting was dissolved at 10:15 P. M.

ANNUAL REPORTS

1949-1950

Report on Deaths, Resignations, and the Status of the Membership: 1949-1950

I regret to have to report the following deaths: Twenty-eight Fellows and two Fellows Emeriti — Oakes Ames (II:2), Wallace Walter Atwood (II:1), William Nickerson Bates (IV:3), Harry Augustus Bigelow (III:1), Robert Pierpont Blake (IV:2), Isaiah Bowman (II:1), Morris William Croll (IV:3), Tyler Dennett (III:2), Harry Manley Goodwin (I:2), Dennis Robert Hoagland (II:2), William Hovgaard (FE I:4), Leland Ossian Howard (II:3), Percy Rogers Howe (II:4), William Jackson Humphreys (II:1), John George Jack (II:2), Frank Baldwin Jewett (I:4), Elton Mayo (FE III:3), George Richards Minot (II:4), DeWitt Henry Parker (IV:1), Alfred Rehder (II:2), Roland George Dwight Richardson (I:1), Josef Alois Schumpeter (III:3), Sidney Post Simpson (III:1), David Stanley Smith (IV:4), Henry Monmouth Smith (I:3), Virgil Snyder (I:1), Francis Trow Spaulding (III:3), Edward Lee Thorndike (IV:1), Charles Alfred Weatherby (II:2), Herbert Eustis Winlock (IV:4); Two Foreign Honorary Members — August Krogh (II:3), Henri Rabaud (IV:4).

Eight Fellows have been classed as Emeriti: Lyman James Briggs (I:2), Jerome Davis Greene (III:4), William Guild Howard (IV:3), Fred Bates Lund (II:4), Chandler Rathfon Post (IV:4), Frederick Fuller Russell (II:4), Maurice deKay Thompson (I:2), Abbott Payson Usher (III:3).

Four Fellows have resigned: George Wells Beadle (II:1), Herbert John Davis (III:4), Beardsley Ruml (III:4), Frederic Lyman Wells (IV:1).

In May, 1949, ninety-nine Fellows and five Foreign Honorary Members were elected to the Academy; all except four Fellows (Lars Valerian Ahlfors, Henry Cabot Lodge, Jr., Eugene Meyer, Reinhold Niebuhr) accepted election.

The roll now includes 848 Fellows, 49 Fellows Emeriti, and 127 Foreign Honorary Members (exclusive of those elected in 1950).

Respectfully submitted,

May 10, 1950 JOHN W. M. BUNKER, *Secretary*

Report of the Treasurer

Informal comments given by the Treasurer at the Annual Meeting and extracts (Receipts and Expenditures) *from the full report.**

The receipts for the year show a total increase of $11,000 over the previous year. Of this, $6,000 is accounted for by the payment received from the Linda Hall Library in connection with the publication exchange arrangement. There was an increase also in the amount received from the income of the Permanent Science Fund amounting to $2,300. The increase for the Academy General Account, derived from investment income, house charges, and assessments and admission fees, was $1,300 in excess of last year.

The expenditures show a decrease of $6,000. In the Academy general account, the decrease was $2,300, with the house maintenance figure up and appropriations for special alterations down. The amount of the grants from the Permanent Science Fund were up $13,000 and there was an increase of approximately $4,200 in the grants and expenses of the Rumford Fund but these were more than offset by the trifling expenditure from the Amory Fund as against the $22,000 awarded last year (septennial award).

Investments. There have been a number of changes in the securities held in the investment accounts during the year, resulting in a slight decrease in book value. But the improvement in the account comes as a result of something the Treasurer and the Investment Committee have nothing to do with, namely, the rise in market prices. Instead of having a market value of $34,000 less than the book value, as was the case last year, the situation is reversed and the market value as of March thirty-first exceeded the book value by $20,000. The income from these securities shows a yield on the book value of just over 5% which is about as high as even a tax-exempt institution ought to expect, having in mind safety of principal. The account is a bit high in stocks — but they are good stocks — and there is sufficient elbow room to provide purchasing power, should market prices fall substantially, through the considerable holding of U.S. Treasury bonds.

Operating Accounts and Funds. A summary of operating accounts will show that the balances have increased about $4,000 over the year before. A really significant gain is in the Current Expense Fund which was increased by transfer of the excess of income over expenditures for last year of $3,207 and this brings the total of this Current Expense Fund to over $7,000 available for current purposes. The $6,000 received from the Linda Hall Library on account of the exchanged publications has been set up as a special fund and appears in the list for the first time.

---

*Printed copies of the full Report of the Treasurer were distributed at the Annual Meeting and may be had on request from the office of the Academy.

Receipts*

Academy, General:			
Investment Income	$35,651.97		
Less: Income to Special Funds	15,396.75		
		$20,255.22	
House Charges		3,895.90	
Assessments and Admission Fees		7,922.50	
			$32,073.62
Mabel S. Agassiz Fund:			
Investment Income			115.00
Amory Fund Committee:			
Investment Income			3,392.50
Linda Hall Library Publication Exchange Fund			6,000.00
Kennelly Fund:			
Investment Income			92.00
Life Membership Fund:			
From Charles B. Higgins			200.00
Permanent Science Fund:			
Boston Safe Deposit and Trust Co., Trustee		$13,000.00	
Return of Grants		461.07	
Investment Income		2,875.00	
			16,336.07
Publications Committee:			
Investment Income		$ 3,030.25	
Sale of Publications		1,795.49	
Lake Publications		103.50	
Appropriation — General Funds		3,000.00	
			7,929.24
Rockefeller Foundation Fund:			
Institute for the Unity of Science			3,000.00
Rumford Fund Committee:			
Investment Income			4,776.50
School Science Fund:			
Contributions			350.00
Special Endowment Fund:			
Contribution		$ 200.00	
Investment Income		5.75	
			205.75
Warren Fund Committee:			
Investment Income			1,109.75
Total Receipts			$75,580.43

*Excluding sales of securities.

EXPENDITURES*

Academy, General:			
Salaries and Pensions		$10,618.15	
Meetings and General Administration		4,170.93	
House Maintenance		8,919.88	
President's Expense		312.39	
Treasurer's Expense		710.34	
Special Appropriations:			
Committee on International Relations	$ 134.30		
World Congress of Mathematics	1,000.00		
Publications Committee	3,000.00		
		4,134.30	
			$28,865.99
Mabel S. Agassiz Fund:			
For Meetings			115.00
Amory Fund:			
Expense			82.63
Institute for the Unity of Science			1,122.36
Permanent Science Fund:			
Grants		$25,747.00	
Expense		433.62	
			26,180.62
Publications Committee:			
Bulletin		$ 1,328.54	
Proceedings		4,989.35	
Miscellaneous		145.92	
			6,463.81
Rumford Fund Committee:			
Grants		$ 3,950.00	
Medals		634.10	
Expense		884.95	
			5,469.05
School Science Fund			2,261.54
Warren Fund Committee:			
Grants			1,430.00
Total Expenditures			$71,991.00

Respectfully submitted,

HORACE S. FORD, *Treasurer.*

May 10, 1950

*Excluding purchases of securities.

Report of the House Committee

The Academy made use of its House for its own meetings during the past year about fifty times. Besides the eight stated meetings, there were over forty meetings of various committees, seminars, and conferences held under the auspices of the Academy. This makes an average of about one meeting a week. Attendance averaged about forty, ranging from half a dozen to two hundred. Twenty-eight guest organizations held 129 different meetings with an average attendance of 78. There were six exhibits displayed in the lobby from time to time during the year which attracted an estimated 2,000 visitors, so that the total number entering the building, except in connection with the offices, was about 14,000, which is approximately the same as estimated for last year. Since there are practically no meetings from the end of May to the end of September, there is an average of over five meetings a week during the meeting season. A table below lists the various guest organizations and the number of meetings held by them.

	No. of Meetings
Alliance Française (two meetings with Salon Français)	7
Alpha Phi Sorority, Graduates of Salem Teachers College	1
American Association of University Women, Boston Branch	1
American Historical Association	3
Artists Equity Foundation	1
Boston Authors Club	10
Boston Institute	1
Boston Psychoanalytic Society and Institute	9
Boston Public School Art League	1
Boston Society of Civil Engineers	4
Boston Teachers Union	10
Brookline Bird Club	2
Children's Museum Trustees	4
Dynamion Society	18
Eastern Association of Physics Teachers (Board meeting)	1
English Speaking Union	1
French Center of New England	9
French Library in Boston	1
High School Women's Club of Boston	1
Joyce Kilmer Post, American Legion	14
Mediaeval Academy	2
New England Botanical Club	9
New England Council of Camera Clubs	1
New England Farm and Garden Association	8
New England Section of Optical Society of America	4
Radcliffe Alumnae, Graduate Chapter	1
Rhodes Scholarship Committee	1
Swedish-American Council	4
Total	129

Exhibits

Polio Exhibit
Historic Photographs (1864-1941)
Abbott H. Thayer—Discoveries in Protective Coloration
Edgerton's High Speed Photography
U. S. Camera Annual
Parker Medal Exhibition

The use of the House for office purposes continues as before, with the two Academy offices (with a regular staff of three) on the first floor, and the office of the Cooperative Broadcasting Council of the Lowell Institute (with a regular staff of ten) and the Committee on International (formerly Inter-American) Scientific Publication (with a regular staff of three) on the fourth floor. The Boston Museum of Science and the Boston Authors Club continue to store their libraries in the book-stack wing. We continue to receive requests from other scientific and cultural organizations who would like office space in our House but for whom at present we have no room.

The costs of maintaining and operating the House are given in a table below.

Expenditures	
Coal	$ 1,360.95
Gas	22.99
Electricity	1,303.71
Elevator	536.98
Water	111.95
Equipment	118.40
Supplies	453.47
Alterations and Repairs	1,697.56
Fire Insurance	552.27
Custodian and Assistance	2,652.40
Custodian, Pension (listed separately by Treasurer)	600.00
Miscellaneous	109.20
Total	$ 9,519.88
Appropriations	
House Maintenance, supplies	$ 6,407.24
Custodian and Assistance	2,780.00
Custodian, Pension	600.00
Total	$ 9,787.24
Unexpended	267.36
	$ 9,519.88

In March, 1949, charges for use of facilities were estimated for the fiscal year 1949-1950 at	$ 4,347.00
Actual receipts amounted to	3,895.90
Estimates thus exceeded receipts by	$ 451.10

Total expenditures	$ 9,519.88
Less actual receipts	3,895.90
Net cost of House Maintenance and Operations	$ 5,623.98

By adding to the above-listed expenditures totaling roughly $9,500, the $800 which the Executive Officer informs me is the approximate cost of administration of House affairs by his office, we find an over-all cost of about $10,300 for operations and maintenance under current conditions.

While our guests occupied about 60 percent of the building, we asked them to contribute only about 37 percent ($3,895.90) towards the maintenance and operating costs, but nothing, of course, towards investment value or the depreciation or replacement costs of the building. I was pleased that we were able to keep expenditures for the fiscal year within one percent of the amount allotted in March, 1949, and that we actually spent about $250 less than all monies appropriated.

No major repairs or alterations were made during the year. About $500 was spent on reupholstering furniture in the Lounge, about $600 on plumbing repairs, $172 for a Bulletin Board on the outside of the House, and about $300 on elevator repairs. The exhaust fan which ventilates the Lecture Hall was put in operation after many years' disuse. The operating expenses were essentially the same as last year.

A portrait of Benjamin Peirce (1809-1880), a former member of the Academy, was donated to us by Mr. Benjamin Peirce Ellis; and it has been cleaned and rebacked, and the frame repaired.

I am indebted to the office staff for their administration of the affairs of the House during the year, and for a detailed analysis of the costs of operations and maintenance in relation to the use of the House by ourselves and our guest occupants. We are especially indebted to the faithful services of Mr. and Mrs. Waters who, with some part-time assistance, are on duty at all hours from before daybreak often until midnight or after, and who have provided not only for the routine cleaning and care of the House but also have on their own initiative made improvements. Mr. Waters' friendly and capable service is well known at meetings of both the Academy and its guests.

Respectfully submitted,

CHESTER M. ALTER, *Chairman*

May 10, 1950

Report of the Committee on Publication

The Committee held three formal meetings during the year and conducted considerable business by correspondence and telephone.

There was one special publication during the year: *Health Services for Massachusetts Children* by Lendon Snedeker. This monograph, mentioned in the reports for 1947 and 1948, appeared in the summer, 1949, with the imprint: "Published for the Massachusetts Study of Child Health Services by The American Academy of Arts and Sciences." This excellent survey was accepted for publication by the Committee and conforms with our editorial styles and practices. It is the most considerable so far of the informal series of special publications issued in accordance with the suggestions contained in the Mather Report, that the Academy should be more closely linked with community activities.

No numbers of the *Memoirs* or books appeared during the year and no manuscripts for such publications are in hand, though several are in prospect.

Volume 77 of the *Proceedings* was completed with the publication of the ninth, the Summer Number, in July, 1949. It contained 372 pages as compared with the 160 double-column pages of Volume 76. Of Volume 78 two numbers have appeared; the third and fourth are in press. The fifth, the statutory Summer Number, will bring the volume to about 300 pages, the size that the Committee on Publication has decided should be the maximum for the present.

The *Bulletin*, under the direction of Mr. Burhoe, has been issued eight times.

The Committee on Publication had $7,929.24 at its disposal for the fiscal year. It had expended by April first $6,463.81 as compared with $7,415.05 in the preceding twelve-month. This difference represents almost exactly the decrease in the total budget from the preceding year, one thousand dollars. The *Proceedings* now in press and the cost of two numbers of the *Bulletin* and bills to the amount of $1,539.56 approved on the last day of the past fiscal year are included in the budget of the new year. The *Bulletin* cost $1,328.54 as compared with $1,104.13 last year, the difference being caused not by an increase in printing costs. The cost of nine issues was included in the budget for 1949-1950 as against seven issues in 1948-1949. This overlap can sometimes not be avoided. In the year 1949-1950 the investment income and sales totaled $4,929.24, a decrease of $819.48 from the preceding year, which is more than accounted for by the decrease in sales which had stood at an abnormally high figure because of post-war purchases by libraries. The unexpended reserve balance in the Publication account stands at $12,193.58, as compared with $12,394.48 on May 1, 1949.

The problem of printing costs on which the Editor reported last year is no less pressing than it was. There are various possibilities of achieving small savings. But until the over-all situation is clarified the Committee

on Publication will be obliged to limit the amount of publication in number of pages printed. This limitation applies in the first instance to the *Proceedings*. We shall continue to accept special publications that appeal to a wider audience, are protected by a subvention, and can consequently be expected to pay their own way. There are several such publications in prospect for 1950-1951.

Subsequent to the sale of the Academy's library to the Linda Hall Library the Council asked the Committee on Publication to negotiate an agreement with the Linda Hall Library to cover the disposition of current exchanges. An agreement was made to cover the four years that had elapsed since the sale of the library and a permanent agreement is at present in the final stages of negotiation.

Respectfully submitted,

TAYLOR STARCK, *Chairman*

May 10, 1950

Report of the Permanent Science Fund Committee

In July, 1949, the Permanent Science Fund sent advertisements to seventeen scientific journals. These advertisements were run one or more times in many of these journals without charge to the Fund.

The committee met on October 11, 1949, and again on April 5, 1950, to consider applications for grants-in-aid.

The annual income from the Fund in past years has been approximately $12,000, but in 1949-1950 (through March 31) it was $15,875. During the war few grants were made and a substantial surplus had accumulated.

At the October 11 meeting, $47,656.96 was available for disbursement among thirty-five applicants whose requests totalled $41,472. The committee granted $17,197 to sixteen of these applicants.

At the April 5 meeting the Fund had cash on hand of $51,105.71 (including surplus and income), and at this time there were thirty-seven applications to be considered, totaling $47,005.60. The committee recommended grants to eleven of these for a total of $13,463. This makes a total of $30,660 voted in grants in 1949-1950.

The applications recommended for grants by the Permanent Science Fund Committee at our two meetings were approved by the Council. The grants made during the year are listed below.

1. To William D. Blake, Instructor, Department of Physiology, Yale University School of Medicine, 333 Cedar Street, New Haven 11, Connecticut, *for a study of the effect of experimental cardiac failure on renal blood flow, glomerular filtration rate and electrolyte excretion*, $1,200.

2. To Philip F. Bonhag, Assistant Professor of Entomology, Kansas State College, Manhattan, Kansas, *for a study of the micro-anatomy of the horsefly with special emphasis on the relationship of structure to function*, $485.

3. To Matilda M. Brooks, Research Associate in Physiology, University of California, Berkeley, California, for studies on growth and development of cells as affected by changes in oxidation-reduction potential, $900.

4. To Min Chueh Chang, Research Associate, Worcester Foundation for Experimental Biology, 222 Maple Avenue, Shrewsbury, Mass., for a study of the effects of steroid hormones on the development of rabbit eggs, $1,600.

5. To Leon S. Ciereszko, Assistant Professor of Chemistry, University of Oklahoma, Norman, Oklahoma, for a study of chemistry and metabolism of the D(-)-Glutamic acid polypeptide produced by Bacillus subtilis, $1,350.

6. To Bodie E. Douglas, Assistant Professor of Chemistry, The Pennsylvania State College, State College, Pennsylvania, for an investigation of the "trans" effect in coordination compounds, $300.

7. To Zareh Hadidian, Assistant Professor of Pharmacology, Tufts College Medical School, 416 Huntington Avenue, Boston, Mass., for an investigation of the reaction between hyaluronidases and the thermolabile hyaluronidase inhibitor of the normal serum, $1,500.

8. To Loo-keng Hua, Professor of Mathematics, Tsing Hua University, and Visiting Professor, University of Illinois; and Lowell Schoenfeld, Assistant Professor of Mathematics, University of Illinois, Urbana, Illinois, for preparation of manuscript, Modern Analytic Theory of Numbers, $300.

9. To J. Logan Irvin, Assistant Professor of Physiological Chemistry, The Johns Hopkins University School of Medicine, Baltimore 5, Maryland; and Elinor Moore Irvin, Volunteer, for a physico-chemical study of the interaction of quinoline and acridine derivatives with nucleic acids and nucleoproteins, $1,000.

10. To John James, Instructor, Department of Sociology, University of Oregon, Eugene, Oregon, for a comparative study of small group size in the formal and informal organization of an industrial plant, $1,000.

11. To Irving Allan Kaye, Chemistry Instructor, Brooklyn College, Bedford Ave. & Avenue H., Brooklyn, New York, for the preparation of Para-Amino-alkoxyanilines and 2-Amino-6-(aminoalkoxy) benzthiazols as potential pharmaceuticals, $1,200.

12. To Albert Kelner, Research Associate, Biological Laboratories, Harvard University, Cambridge 38, Mass., for a study of the mechanism of light-reactivation of ultraviolet irradiated bacteria, $900.

13. To Frederick G. Keyes, Professor of Physical Chemistry, Mass. Institute of Technology, Cambridge 39, Mass., for a study of the heat conductivity of gases to pressures of 100 atm. and to temperatures of 400° C., $1,500.

14. To Michel Macheboeuf, Professor, Institut Pasteur, 28 rue du Docteur Roux, Paris XV, France, for a study of lipoproteins, $2,000.

15. To Norten C. Melchior, Assistant Professor of Biochemistry, Stritch School of Medicine, Loyola University, 706 S. Wolcott Street, Chicago 12, Illinois, for a study of models for biological processes—the study of metal-organic complex compounds, $1,412.

16. To Giuseppe Moruzzi, Professor of Physiology and Head of the Department of Physiology, University of Pisa, Via S. Zeno 13, Pisa, Italy,

for an investigation of the mechanism of the cortical arousal reactions, $1,500.

17. To Irvine H. Page, M.D., Director, Research Division, Cleveland Clinic Foundation, 2040 East 93rd Street, Cleveland 6, Ohio, for a study of the histopathology of vascular tissues by electron microscopy, $1,500.

18. To John W. Patterson, Assistant Professor of Anatomy, School of Medicine, Western Reserve University, Cleveland 6, Ohio, for a study of the role of ascorbic and dehydroascorbic acids in metabolism, $2,000.

19. To David D. Perkins, Instructor in Biology, Stanford University, Stanford, California, for a study of genetics of *Ustilago maydis:* Physiological and biochemical mutants, tetrad analysis and mapping, $1,500.

20. To Sara Jane Rhoads, Instructor in Chemistry, University of Wyoming, Laramie, Wyoming, for a study of the mechanism of the Claisen rearrangement of allyl-type ethers of phenols and enols, $1,000.

21. To Sydney C. Rittenberg, Assistant Professor of Bacteriology, University of Southern California, Los Angeles 7, California, for a study of the mechanism of fatty acid oxidation by bacteria, $500.

22. To O. H. Robertson, Professor of Medicine, University of Chicago, Chicago 37, Illinois, for a study of the physiology of the dermal melanophores in the rainbow trout, with especial reference to hormonal and neurohumeral influences, $750.

23. To Jay S. Roth, Assistant Professor of Biochemistry, Bureau of Biological Research, Rutgers University, New Brunswick, New Jersey, for a study of the effects of certain carcinogenic agents on the growth rate and respiration of tetrahymena geleii, $400.

24. To Harlow Shapley, Director, and Bart J. Bok, Associate Director, Harvard Observatory, Cambridge 38, Massachusetts, for an objective prism for the study of spectra of faint southern stars, $2,500.

25. To Harry Sobotka, Chief Chemist, The Mount Sinai Hospital, Fifth Avenue and 100th Street, New York 29, New York, for the quantitative microanalysis of keto-steroids, $1,250.

26. To John F. Taylor, Assistant Professor of Biological Chemistry, Washington University School of Medicine, Euclid and Kingshighway, St. Louis 10, Missouri, for a study of the physicochemical characterization of enzyme proteins at low temperatures, $963.

27. To Carl Louis Wilson, Professor of Botany, Dartmouth College, Hanover, New Hampshire, for a study of vasculation of the stamen in the melastomaceae, with some phyletic implications, $150.

Respectfully submitted,

May 10, 1950 HUDSON HOAGLAND, *Chairman*

Report of the Rumford Committee

The Rumford Committee reports that during the year 1949-1950 the following grants-in-aid of research, totalling $1,150, have been made:

1. To Dr. C. M. Huffer, Secretary of the American Astronomical Society

and Professor of Astronomy in Washburn Observatory, Madison, Wisconsin, in order to assist in his analysis of photoelectric light curves of eclipsing binaries on the occasion of a visit to the Center of Analysis of the Massachusetts Institute of Technology from February to May, 1950, $400.

2. To Dr. Willem J. Luyten, Department of Astronomy, University of Minnesota, to aid in the purchase of photographic supplies for a joint research of the University of Minnesota and the Argentinian observatory at Cordoba, $250.

3. To Dr. E. M. Purcell, Professor of Physics at Harvard University, to assist in microwave experiments on radiation from interstellar space, $500.

The Rumford Fund booklet has been issued in a revised edition of forty pages, published both in the *Proceedings*, Volume 78, No. 2, and separately, at a total printing cost to the Rumford Fund of $792.

The Rumford Premium for 1949 was awarded on December 14, 1949, to Dr. Ira S. Bowen, Director of Mt. Wilson and Palomar Observatories, for his solution of the mystery of nebulium and for other outstanding work in spectroscopy.

The Treasurer reports that the unexpended income of the Rumford Fund as of March 31, 1950, was $21,797.99.

Respectfully submitted,

May 10, 1950 HARLOW SHAPLEY, *Chairman*

Report of the Cyrus M. Warren Committee

The Committee had available for grants the sum of $1,500, which amount was voted by the Council at the meeting on March 9, 1949, for awards during the year 1949-1950.

At a meeting of the Committee on May 27, 1949, the following grants were voted:

1. To Dr. Charles L. Bickel of the Phillips Exeter Academy, a grant of $100 for supplies to continue research in organic chemistry for which previous grants were made in 1947 and 1948.

2. To Professor David W. Bishop of the University of Massachusetts, a grant of $300 for polarizing microscopic apparatus to be used in a biochemical investigation.

3. To Professor Francis J. Reithel of the University of Oregon, a grant of $250 for the purchase of a Warburg Respirometer equipment.

4. To Professor David A. Shirley of Tulane University, a grant of $100 to assist in obtaining a fractionating column and the necessary accessories.

5. To Professor Carl M. Stevens of the State College of Washington, Pullman, Washington, a grant of $385 for equipment needed in the investigation of the occurrence of D-Amino Acids in various organisms.

6. To Dr. Frederic E. Stynler of The Mount Sinai Hospital, New York, a grant of $125 to assist in the construction of apparatus for use in research—a method permitting especially high activation of carbon.

In August, 1949, a letter was received from Professor Bishop relinquishing the grant of $300 and explaining the reason for not accepting the money, namely: changes in research plans whereby the money would not be used for the purpose specified in his application.

In November, 1949, in accordance with a vote taken by mail on an application by M. Kent Wilson of Harvard University, a grant of $470 for use in connection with research on molecular spectroscopy was awarded to Dr. Wilson.

Seven grants were actually voted, totalling $1,730.

A letter from Professor F. J. Reithel reported on satisfactory progress in his research which, it is expected, will continue to the point of publication of results.

A report of progress from Professor E. R. Atkinson of the University of New Hampshire announces the continuation of the work, and includes reprints:

A Polarographic Examination of Diazotized Amines by E. R. Atkinson, H. H. Warren, P. I. Abell and R. E. Wing, J. Am. Chem. Soc., *72*, 915 (1950).

The following reprints have also been received:

The Addition of Benzene to an Acetylenic Ketone by C. L. Bickel and A. J. Fabens, J. Am. Chem. Soc., *71*, 1450 (1949).

Changes in the Carbohydrate Metabolism of Taraxacum Kok-Saghyz Rod during the First and Second Years of Growth by G. Krotkov, Plant Physiology, *25*, 169 (1950).

Respectfully submitted,

May 10, 1950 FREDERICK G. KEYES, *Chairman*

Report of the Amory Prize Committee

The Amory Prize Committee held one meeting with all members present on November 9, 1949.

The Committee reviewed the list of persons suggested for consideration for the third septennium ending on November 10, 1954. Most of these suggestions had been submitted by former recipients of the Amory Prize, either at their joint meeting with the Committee on December 8, 1948, or in response to the letter sent to them by the Chairman of the Committee as a follow-up of that joint meeting.

No especially outstanding new suggestion for the prize developed from this review or was mentioned by a member of the Committee. The Secretary, Dr. Hoskins, urged that all members of the Committee keep alert to indications of good work in the field of the Amory Prize as they came along in the scientific literature and send notes of any of their suggestions to Mr. Burhoe for the files of the Committee.

Respectfully submitted,

May 10, 1950 EDWIN B. WILSON, *Chairman*

ELECTIONS

*May 10, 1950

OFFICERS

Howard M. Jones..*President*
Jerome C. Hunsaker...........................*Vice-President for Class I*
Irving W. Bailey..............................*Vice-President for Class II*
Robert B. Stewart............................*Vice-President for Class III*
William A. Jackson...........................*Vice-President for Class IV*
Henry B. Phillips..*Secretary*
Horace S. Ford..*Treasurer*
Ernest H. Huntress.......................................*Librarian*
Taylor Starck ....*Editor*

Councillors to serve for Four Years

Fred L. Whipple, *of Class I*
Martin J. Buerger, *of Class II*
Stanley E. Qua, *of Class III*
Willard V. O. Quine, *of Class IV*

House Committee

Chester M. Alter, *Chairman*

Charles H. Taylor
John B. Wilbur

Committee on Membership

The President, *Chairman, ex officio*

To serve for two years:

William T. Martin, *of Class I*
John R. Loofbourow, *of Class II*
Arthur N. Holcombe, *of Class III*
Clyde K. M. Kluckhohn, *of Class IV*

Committee on Meetings

The President, *Chairman, ex officio*
The Four Vice-Presidents, *ex officiis*
The Secretary, *ex officio*

Avery A. Morton, *of Class I*
Frederick L. Hisaw, *of Class II*
Mark DeW. Howe, *of Class III*
Henry A. Murray, Jr., *of Class IV*

Committee on Finance

The Treasurer, *Chairman, ex officio*

Ralph E. Freeman
Jerome C. Hunsaker
Henry P. Kendall
Henry L. Shattuck

Auditing Committee

Thomas H. Sanders
Donald S. Tucker

Committee on Publication

The Editor, *Chairman, ex officio*

Ernest H. Huntress
Kenneth B. Murdock
Kenneth V. Thimann
Thomas North Whitehead

Permanent Science Fund Committee

Hudson Hoagland, *Chairman*

Gustavus J. Esselen	Donald H. Menzel	Talcott Parsons
A. Baird Hastings	Edward L. Moreland	Julius A. Stratton

Rumford Committee

Harlow Shapley, *Chairman*

Percy W. Bridgman	George R. Harrison	Edwin H. Land
Arthur C. Hardy	Joseph H. Keenan	Francis O. Schmitt

C. M. Warren Committee

Frederick G. Keyes, *Chairman*

Edwin J. Cohn	Charles A. Kraus	Avery A. Morton
Louis F. Fieser	Eugene M. Landis	Walter C. Schumb

Amory Prize Committee

Edwin B. Wilson, *Chairman*

William B. Castle	Gregory Pincus	George B. Wislocki
Roy G. Hoskins	George W. Thorn	S. Burt Wolbach

FELLOWS

Class I, Mathematical and Physical Sciences

Section 1, Mathematics and Astronomy

Ira Sprague Bowen
Mount Wilson and Palomar Observatories, Pasadena, Calif.
Eric Reissner..........Massachusetts Institute of Technology, Cambridge

Section 2, Physics

Carl David Anderson...California Institute of Technology, Pasadena, Calif.
Francis Bitter..........Massachusetts Institute of Technology, Cambridge
Edward Mills Purcell....................Harvard University, Cambridge
Norman Foster Ramsey..................Harvard University, Cambridge
Laszlo Tisza............Massachusetts Institute of Technology, Cambridge
Merle Antony Tuve...............Carnegie Institution, Washington, D. C.
Eugene Paul Wigner...............Princeton University, Princeton, N. J.

Section 3, Chemistry

William Francis Giauque.........University of California, Berkeley, Calif.
Richard Collins Lord....Massachusetts Institute of Technology, Cambridge

Section 4, Technology and Engineering

Gordon Stanley Brown...Massachusetts Institute of Technology, Cambridge
Morris Cohen...........Massachusetts Institute of Technology, Cambridge
William Rede Hawthorne.Massachusetts Institute of Technology, Cambridge
Robert Victor Kleinschmidt...............Harvard University, Cambridge
Cyril Stanley Smith...................University of Chicago, Chicago, Ill.
John George Trump.....Massachusetts Institute of Technology, Cambridge

Class II, Natural and Physiological Sciences

Section 1, Geology, Mineralogy, and Physics of the Globe

Carl Owen Dunbar....................Yale University, New Haven, Conn.
Beno Gutenberg.......California Institute of Technology, Pasadena, Calif.
Donnel Foster Hewett....United States Geological Survey, Pasadena, Calif.
Arville Irving Levorsen.....................Stanford University, Calif.
Thomas Brennan Nolan..United States Geological Survey, Washington, D. C.

Section 2, Botany

Elso Sterrenberg Barghoorn..............Harvard University, Cambridge
Lincoln Constance...............University of California, Berkeley, Calif.
Adriance Sherwood Foster........University of California, Berkeley, Calif.
Cornelis Bernadus Van Niel
Hopkins Marine Station, Stanford University, Calif.
Philip Rodney White......Institute for Cancer Research, Philadelphia, Pa.
William Lawrence White.................Harvard University, Cambridge

Section 3, Zoology and Physiology

Warder Clyde Allee..................University of Chicago, Chicago, Ill.
Leslie Clarence Dunn...............Columbia University, New York, N. Y.
Roy Orval Greep.......................Harvard University, Cambridge
Carl Richard Moore..................University of Chicago, Chicago, Ill.
Harold Henry Plough........................Amherst College, Amherst
Ralph Walter Graystone Wyckoff
United States Public Health Service, Bethesda, Md.

Section 4, Medicine and Surgery

George Packer Berry.....................Harvard Medical School, Boston
Oliver Cope...........................Harvard Medical School, Boston
Lewis Dexter..........................Harvard Medical School, Boston
Geoffrey Edsall.............Boston University School of Medicine, Boston
Frank Howard Lahey............................Lahey Clinic, Boston
James Howard Means.............Massachusetts General Hospital, Boston
Ira Theodore Nathanson................Harvard Medical School, Boston
Samuel Proger...............................Tufts Medical School, Boston
John Crayton Snyder............Harvard School of Public Health, Boston

Class III, The Social Arts

Section 1, Jurisprudence

Henry Bromfield Cabot..................................Lawyer, Boston
Zechariah Chafee, Jr.....................Harvard Law School, Cambridge
Thomas Harrison Mahony.............................Lawyer, Boston

Section 2, Government, International Law, and Diplomacy

Elmer Holmes Davis...American Broadcasting Company, Washington, D. C.
Saville Rogers Davis...................Christian Science Monitor, Boston

Paul Howard Douglas............United States Senate, Washington, D. C.
Merle Fainsod..........................Harvard University, Cambridge
James William Fulbright.........United States Senate, Washington, D. C.
John Merriman Gaus....................Harvard University, Cambridge
Christian Archibald Herter
United States House of Representatives, Washington, D. C.
Edward R. Murrow.......Columbia Broadcasting System, New York, N. Y.
Anna Eleanor Roosevelt
United Nations Commission on Human Rights, Lake Success, N. Y.

Section 3, Economics and Sociology

Carter Goodrich..................Columbia University, New York, N. Y.
Mark Arthur May....................Yale University, New Haven, Conn.
Robert King Merton...............Columbia University, New York, N. Y.
Harold Glenn Moulton........The Brookings Institution, Washington, D. C.
Samuel Andrew Stouffer..................Harvard University, Cambridge

Section 4, Administration and Affairs

Barry Bingham
Courier Journal and Louisville Times Company, Louisville, Ky.
John Ely Burchard......Massachusetts Institute of Technology, Cambridge
Victor Lloyd Butterfield..........Wesleyan University, Middletown, Conn.
William Terry Couch............University of Chicago Press, Chicago, Ill.
Charles Dollard.......Carnegie Corporation of New York, New York, N. Y.
Alan Gregg................The Rockefeller Foundation, New York, N. Y.
William Averell Harriman
Economic Cooperation Administration, Washington, D. C.
Helen Rogers Reid........The New York Herald Tribune, New York, N. Y.
George Nauman Shuster.................Hunter College, New York, N. Y.
Arthur Hays Sulzberger...........The New York Times, New York, N. Y.
William Webster
United States Research and Development Board, Washington, D. C.
Thomas James Wilson...............Harvard University Press, Cambridge
Benjamin Fletcher Wright...................Smith College, Northampton

CLASS IV, THE HUMANITIES

Section 1, Theology, Philosophy, and Psychology

John La Farge
Editor, America, National Catholic Weekly, New York, N. Y.
Gardner Murphy........College of the City of New York, New York, N. Y.
Herbert Wallace Schneider.........Columbia University, New York, N. Y.
Paul Johannes Tillich........Union Theological Seminary, New York, N. Y.

Section 2, History, Archaeology, and Anthropology

Herbert Bloch..........................Harvard University, Cambridge
Helen Maud Cam.........................Harvard University, Cambridge

Sterling Dow............................Harvard University, Cambridge
Hetty Goldman............Institute for Advanced Study, Princeton, N. J.
Louis Gottschalk.....................University of Chicago, Chicago, Ill.
Michael Karpovich.......................Harvard University, Cambridge
Ralph Linton........................Yale University, New Haven, Conn.
Conyers Read.............University of Pennsylvania, Philadelphia, Penn.
Robert Redfield.......................University of Chicago, Chicago, Ill.
Dixon Wecter...................University of California, Berkeley, Calif.

Section 3, Philology

Roman Jakobson........................Harvard University, Cambridge
Harry Tuchman Levin....................Harvard University, Cambridge
Charles Southward Singleton..............Harvard University, Cambridge

Section 4, The Fine Arts and Belles Lettres

E. Power Biggs.................Organist and musical scholar, Cambridge
John Nicholas Brown
Assistant Secretary of Navy for Air, Washington, D. C.
Luther Harris Evans.............Library of Congress, Washington, D. C.
William Mills Ivins, Jr......Metropolitan Museum of Art, New York, N. Y.
Archibald MacLeish......................Harvard University, Cambridge
John Phillips Marquand..........................Author, Newburyport
Charles Münch......................Boston Symphony Orchestra, Boston
Charles Henry Sawyer................Yale University, New Haven, Conn.

FOREIGN HONORARY MEMBERS

CLASS I, MATHEMATICAL AND PHYSICAL SCIENCES

Section 1, Mathematics and Astronomy

Henri Cartan................................University of Paris, Paris

Section 2, Physics

Sir John Douglas Cockcroft
Atomic Energy Research Establishment, Harwell, England
Paul Adrien Maurice Dirac..............Cambridge University, Cambridge
Wolfgang Pauli.....................Eidg. Technische Hochschule, Zürich
Erwin Schrödinger.........Dublin Institute for Advanced Studies, Dublin

Section 3, Chemistry

George De Hevesy......University of Stockholm, University of Copenhagen

Section 4, Technology and Engineering

Adolph Meyer...................Brown, Boveri & Co., Baden, Switzerland

CLASS II, NATURAL AND PHYSIOLOGICAL SCIENCES

Section 2, Botany

Hendrik Gunnar Lundegardh.......Institute of Plant Physiology, Uppsala

Section 3, Zoology and Physiology

Kaj Ulrik Linderström-Lang..........Carlsberg Laboratories, Copenhagen
Rudolph Albert Peters.......................Oxford University, Oxford
Hugo Theorell...............................Nobel Institute, Stockholm

Section 4, Medicine and Surgery

Wilder Graves Penfield.....................McGill University, Montreal

CLASS III, THE SOCIAL ARTS

Section 2, Government, International Law, and Diplomacy

Herbert Vere Evatt................................Canberra, Australia
Trygve Halvdan Lie.................United Nations, Lake Success, N. Y.
Jawaharlal Nehru.......................Prime Minister, New Delhi, India
Paul-Henri Spaak ....Brussels

CLASS IV, THE HUMANITIES

Section 1, Theology, Philosophy, and Psychology

Karl Barth.................................University of Basle, Basle
Sir William David Ross............................Oriel College, Oxford

Section 2, History, Archaeology, and Anthropology

George Norman Clark...........................Oriel College, Oxford
John Ernest Neale.......................University of London, London

Section 3, Philology

Roger Aubrey Baskerville Mynors........Cambridge University, Cambridge

Section 4, The Fine Arts and Belles Lettres

Sir Stanley Unwin........................George Allen & Unwin, London
Rebecca West..........................Author, Ibstone, Bucks, England

INDEX FOR VOLUME 78

A. Index of Papers by Author and by Title

B. Index to Affairs of the American Academy of Arts and Sciences

Date of Issue	Date of Issue	Date of Issue